



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Dark matter interpretations of ATLAS searches for the electroweak production of supersymmetric particles in  $\sqrt{s}=8$  TeV proton-proton collisions



# Dark matter interpretations of ATLAS searches for the electroweak production of supersymmetric particles in $\sqrt{s} = 8$ TeV proton-proton collisions



## The ATLAS collaboration

*E-mail:* [atlas.publications@cern.ch](mailto:atlas.publications@cern.ch)

**ABSTRACT:** A selection of searches by the ATLAS experiment at the LHC for the electroweak production of SUSY particles are used to study their impact on the constraints on dark matter candidates. The searches use  $20\text{ fb}^{-1}$  of proton-proton collision data at  $\sqrt{s} = 8\text{ TeV}$ . A likelihood-driven scan of a five-dimensional effective model focusing on the gaugino-higgsino and Higgs sector of the phenomenological minimal supersymmetric Standard Model is performed. This scan uses data from direct dark matter detection experiments, the relic dark matter density and precision flavour physics results. Further constraints from the ATLAS Higgs mass measurement and SUSY searches at LEP are also applied. A subset of models selected from this scan are used to assess the impact of the selected ATLAS searches in this five-dimensional parameter space. These ATLAS searches substantially impact those models for which the mass  $m(\tilde{\chi}_1^0)$  of the lightest neutralino is less than  $65\text{ GeV}$ , excluding 86% of such models. The searches have limited impact on models with larger  $m(\tilde{\chi}_1^0)$  due to either heavy electroweakinos or compressed mass spectra where the mass splittings between the produced particles and the lightest supersymmetric particle is small.

**KEYWORDS:** Hadron-Hadron scattering (experiments)

**ARXIV EPRINT:** [1608.00872](https://arxiv.org/abs/1608.00872)

---

## Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>ATLAS searches</b>	<b>3</b>
<b>3</b>	<b>Theoretical framework</b>	<b>4</b>
3.1	Scanning strategy	4
3.2	Experimental constraints in the initial likelihood scan	6
3.3	Phenomenology of the LSP	9
<b>4</b>	<b>Signal simulation and evaluation of ATLAS constraints</b>	<b>10</b>
<b>5</b>	<b>Impact of the ATLAS electroweak SUSY searches</b>	<b>12</b>
5.1	Impact on the electroweakino masses	12
5.2	Impact on the EWKH model parameters	13
5.3	Impact on dark matter observables	14
<b>6</b>	<b>Conclusions</b>	<b>19</b>
	<b>The ATLAS collaboration</b>	<b>27</b>

---

## 1 Introduction

Supersymmetry, or SUSY [1–6], is a popular candidate for physics beyond the Standard Model. It provides an elegant solution to the hierarchy problem, which, in the Standard Model, demands high levels of fine tuning to counteract large quantum corrections to the mass of the Higgs boson [7–10].  $R$ -parity-conserving supersymmetric models can also provide a candidate for dark matter, in the form of the lightest supersymmetric particle (LSP) [11, 12].

The ATLAS and CMS experiments performed a large number of searches for SUSY during Run-1 of the LHC and, in the absence of a significant excess in any channel, exclusion limits on the masses of SUSY particles (sparticles) were calculated in numerous scenarios, usually in the context of the minimal supersymmetric Standard Model (MSSM) [13, 14]. These scenarios include “high-scale” SUSY models such as mSUGRA [15–17] or GMSB [18–20], both of which specify a particular SUSY-breaking mechanism. Most searches also considered specific “simplified models”, which attempt to capture the behaviour of a small number of kinematically accessible SUSY particles, often through considering one particular SUSY production process with a fixed decay chain.

Although the high-scale and simplified model exclusions provide an easily interpretable picture of the sensitivity of analyses to specific areas of parameter space, they are far from

a full exploration of the MSSM, which contains about 120 free parameters. The number of parameters is reduced if the phenomenological MSSM (pMSSM) is considered instead. It is based on the most general CP-conserving MSSM, with  $R$ -parity conservation, and minimal flavour violation [21, 22]. In addition, the first two generations of sfermions are required to be degenerate and have negligible Yukawa couplings. This leaves 19 independent weak-scale parameters to be considered: ten sfermion masses (five for the degenerate first two generations and five for the third generation), three trilinear couplings  $A_{\tau,t,b}$  which give the couplings between the Higgs field and the third-generation sfermions, the bino, wino and gluino mass parameters  $M_{1,2,3}$ , the higgsino mass parameter  $\mu$ , the ratio of the vacuum expectation values of the Higgs fields  $\tan \beta$ , and the mass of the pseudoscalar Higgs boson  $m_A$ .

The model considered here, henceforth referred to as EWKH, is described by only five parameters:  $M_1$ ,  $M_2$ ,  $\mu$ , and  $\tan \beta$  to define the gaugino-higgsino sector, and  $m_A$  to define the Higgs sector. Both sectors are defined at tree level. The coloured SUSY particles and sleptons are assumed to be heavy such that they do not impact the phenomenology. This model is well motivated from a dark matter perspective since the dark matter candidate of the MSSM is the lightest neutralino whose properties are fully specified by these five parameters. These parameters therefore also determine the relic density of the neutralino for much of the pMSSM parameter space, i.e. if coannihilations with slepton, squarks and gluinos are neglected.

An interpretation of the Run-1 SUSY searches in pMSSM models may be found in the literature (for instance refs. [23–25]). In particular, ATLAS has previously performed a study using about 300 000 pMSSM model points [26]. In that work, all 19 of the pMSSM parameters were varied and the strongest direct constraints on sparticle production were obtained in searches for squarks and gluinos. In this article, attention is restricted to a five-dimensional (5D) sub-space of the pMSSM in order to assess the impact of the ATLAS Run-1 searches (using  $20 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 8 \text{ TeV}$ ) specifically on the electroweak production of SUSY particles, and the corresponding constraints on dark matter. This provides a study complementary to that in ref. [26] by decoupling strong-interaction production processes from the phenomenology, and thus allows more extensive exploration of the regions of parameter space relevant to electroweak production. The scanning strategy used to select models is also different to ref. [26], where models were sampled from uniform distributions in the pMSSM parameters, and then required to satisfy a variety of experimental constraints. In this study, an “initial likelihood scan” is performed to select models, using constraints from direct dark matter searches, precision electroweak measurements, flavour-physics results, previous collider searches, and the ATLAS Higgs boson mass measurement.

The impact of the ATLAS searches in different regions of parameter space is established by considering the number of models selected by the initial likelihood scan that are excluded by the ATLAS electroweak SUSY searches. Exclusion limits are calculated using the  $\text{CL}_s$  technique [27]. Both particle-level<sup>1</sup> and reconstruction-level information is used to calculate the  $\text{CL}_s$  values (see section 4), where the reconstruction-level information makes

---

<sup>1</sup>Particle-level information constructs observables using the stable particles from MC generators, which account for the majority of interactions with the detector material [28].

use of the ATLAS detector simulation, data-driven background estimations, and systematic uncertainties and their correlations. The  $\text{CL}_s$  calculations invoke the simplifying assumption that the reconstruction of events selected at particle level can be parameterised using an average efficiency factor that does not depend on the details of the SUSY model. The reconstruction-level information can then be used to directly map particle-level results to  $\text{CL}_s$  values. This “calibration procedure” significantly reduces the computational load of the analysis and accounts, on average, for the acceptance and efficiency across the ensemble of models.

## 2 ATLAS searches

Four ATLAS Run-1 SUSY searches that target electroweak SUSY production are considered, as listed in table 1. Their combined impact on simplified models of electroweak particle production, as well as selected pMSSM and high-scale models, is summarised in ref. [29].

The  $2\ell$  analysis [30] targets  $\tilde{\ell}$ -pair production and  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  production (where  $\tilde{\chi}_1^\pm$  decays via sleptons) with three signal regions, looking for an excess of events with  $e^+e^-$ ,  $\mu^+\mu^-$  or  $e^\pm\mu^\mp$  and high transverse mass ( $m_{\text{T}2}$ ) [31, 32]. Three additional signal regions target the more difficult scenario of  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  production where the charginos decay via  $W$  bosons. Finally, a seventh signal region requiring an opposite-sign light-lepton pair ( $e^+e^-$ ,  $\mu^+\mu^-$ ) with an invariant mass consistent with a  $Z$  boson and an additional pair of jets is used to target  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production where the chargino decays via a  $W$  boson and the neutralino decays via a  $Z$  boson. The  $2\tau$  analysis [33] uses four signal regions to search for  $\tilde{\tau}$ -pair,  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  and  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production, where the charginos and neutralinos decay via third-generation sleptons. Events with a pair of opposite-sign hadronically decaying  $\tau$ -leptons ( $\tau_{\text{had}}$ ) and large  $m_{\text{T}2}$  are selected for the search. The  $3\ell$  analysis [34] searches for weakly interacting SUSY particles in events with three light leptons ( $e/\mu$ ), two light leptons and one  $\tau_{\text{had}}$ , or one light lepton and two  $\tau_{\text{had}}$ . Twenty-four signal regions are defined to target  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production, where charginos and neutralinos decay via sleptons, staus, or the SM bosons  $W$ ,  $Z$  and  $h$ . The  $4\ell$  analysis [35] searches for higgsino-like  $\tilde{\chi}_2^0 \tilde{\chi}_3^0$  production, where the neutralinos decay via sleptons, staus or  $Z$  bosons. Nine signal regions are used to select events with large missing transverse momentum (whose magnitude is denoted as  $E_{\text{T}}^{\text{miss}}$ ) and four light leptons, three light leptons and one  $\tau_{\text{had}}$ , or two light leptons and two  $\tau_{\text{had}}$ .

Although this article is restricted to these four analyses, other SUSY searches could provide sensitivity in some regions of the parameter space considered in this article. For example, the ATLAS disappearing-track analysis [36] targets direct long-lived charginos with proper lifetimes  $\mathcal{O}(1\text{ ns})$  so it could have sensitivity to compressed models where the mass difference of the lightest chargino and the LSP is much less than 1 GeV. Consideration of this analysis is beyond the scope of this article. Furthermore, the ATLAS monojet search [37] targets pair-produced dark matter particles but makes no assumption of an underlying supersymmetric theory. These results do not yet have sensitivity to direct electroweak SUSY production so is not considered further in this analysis.

Analysis	Target production processes
$2\ell$ [30]	$\tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^\pm \tilde{\chi}_2^0, \tilde{\ell} \tilde{\ell}$
$2\tau$ [33]	$\tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_1^\pm \tilde{\chi}_2^0, \tilde{\tau} \tilde{\tau}$
$3\ell$ [34]	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$
$4\ell$ [35]	$\tilde{\chi}_2^0 \tilde{\chi}_3^0$

**Table 1.** ATLAS electroweak SUSY searches re-interpreted in the pMSSM for this article.

### 3 Theoretical framework

The theoretical SUSY framework used in this article is an effective model of the electroweak gauginos, higgsinos and the Higgs sector of the MSSM, collectively labelled EWKH. The model is described by five parameters, where four of them define the gaugino-higgsino sector at tree level ( $M_1$ ,  $M_2$ ,  $\mu$ , and  $\tan\beta$ ), and  $m_A$  is added to define the Higgs sector at tree level. The other soft sparticle masses are large to ensure that the sfermions and gluinos are decoupled from the effective theory, while the trilinear couplings are not constrained. The specific values used are 5TeV for the sfermion soft-masses, 4TeV for the gluino mass and 0.1TeV for the trilinear couplings.

When scanning in this framework, a Bayesian prior distribution for these parameters is used as a device to concentrate the parameter scan in certain regions of parameter space. Two different prior distributions are adopted: “flat priors” are uniform in all model parameters, while “log priors” are uniform in the logarithm of all model parameters, except for  $\tan\beta$ , for which a uniform prior is used for both sets. Flat priors tend to concentrate sampling towards large values of the parameters (as most of volume of the prior lies there), while log priors concentrate their scan in the lower mass ( $\ll 1\text{TeV}$ ) region (since this metric gives every decade in the parameter values the same a priori probability). The posterior samples resulting from the flat and log prior scans are then merged to achieve a reliable mapping of the (prior-independent) profile likelihood function, as advocated in ref. [38]. Table 2 displays both of the priors used and their ranges.<sup>2</sup> The specific ranges are chosen because they contain the interesting dark matter phenomenology.

The profile likelihood maps obtained from merging the samples gathered with both priors explore in detail both the low-mass and the high-mass regions, for a more thorough scanning of the entire parameter space.

#### 3.1 Scanning strategy

A Bayesian approach is adopted for sampling the EWKH parameter space, and the sensitivity of the ATLAS SUSY electroweak analyses is calculated for the resulting posterior samples. This “initial likelihood scan” is driven by the likelihood defined in section 3.2, which is a function of the five pMSSM model parameters and additional nuisance param-

<sup>2</sup>For parameters that span both negative and positive numbers the log prior is actually a piecewise function in order to be invertible. The log parameter  $\theta'_i$  is mapped onto the linear, physical, parameter  $\theta_i$  as follows: if  $|\theta'_i| \geq \log_{10} e$  then  $\theta_i = \text{sign}(\theta'_i) 10^{|\theta'_i|}$ , otherwise  $\theta_i = \theta'_i e / \log_{10} e$ .

Flat priors		Log priors	
$M_1$ [TeV]	$(-4, 4)$	$\text{sign}(M_1) \log_{10}  M_1 /\text{GeV}$	$(-3.6, 3.6)$
$M_2$ [TeV]	$(0.01, 4)$	$\log_{10} M_2/\text{GeV}$	$(1, 3.6)$
$\mu$ [TeV]	$(-4, 4)$	$\text{sign}(\mu) \log_{10}  \mu /\text{GeV}$	$(-3.6, 3.6)$
$m_A$ [TeV]	$(0.01, 4)$	$\log_{10} m_A/\text{GeV}$	$(1, 3.6)$
$\tan \beta$	$(2, 62)$	$\tan \beta$	$(2, 62)$

**Table 2.** EWKH parameters used in the initial likelihood scan and the prior ranges for the two prior choices adopted. “Flat priors” are uniform in the parameter itself within the indicated ranges, while “log priors” are uniform in the logarithm of the parameter within the indicated ranges. The physical ranges for both priors are identical for both the “flat” and “log” priors.

eters. The dimensionality of the likelihood can be reduced to one or two parameters by maximising the likelihood function over the remaining parameters. The resulting function is called the profile likelihood.

For example, for a single parameter of interest  $\theta_i$  and other undesired parameters  $\Psi = \{\theta_1, \dots, \theta_{i-1}, \theta_{i+1}, \dots, \theta_n\}$  the 1D profile likelihood is defined as:

$$\mathcal{L}(\theta_i) = \max_{\Psi} \mathcal{L}(\theta_i, \Psi) = \mathcal{L}(\theta_i, \hat{\Psi}), \quad (3.1)$$

where  $\mathcal{L}(\theta_i, \Psi)$  is the likelihood function and  $\hat{\Psi}$  is the conditional maximum likelihood estimate (MLE) of  $\Psi$  for a given  $\theta_i$ .

Confidence intervals/regions from the resulting 1D/2D profile likelihood maps are determined by adopting the usual Neyman construction with the profile likelihood ratio  $\lambda(\theta_i)$  as the test statistic:

$$\lambda(\theta_i) = \frac{\mathcal{L}(\theta_i, \hat{\Psi})}{\mathcal{L}(\hat{\theta}_i, \hat{\Psi})}, \quad (3.2)$$

where  $\hat{\theta}_i$  and  $\hat{\Psi}$  are the unconditional MLEs.

Intervals, or regions, corresponding to 68%, 95% and 99% CL can be estimated by assuming  $-2 \ln \lambda(\theta_i)$  is  $\chi^2$ -distributed which is motivated by Wilks’ theorem [39]. This test statistic is used to select the models of interest in this analysis. For each of the final distributions in section 5 the models included are those within the 95% confidence interval/region of the profile likelihood.

The software used to sample the parameter space is **SuperBayeS-v2.0**, which is interfaced with the publicly available code **MultiNest v2.18** [40, 41], an implementation of the nested sampling algorithm [42]. This is an updated and improved version of the publicly available **SuperBayeS** scanning package [43, 44]. This Bayesian algorithm, originally designed to compute a model’s likelihood and to accurately map out the posterior distribution, can also reliably evaluate the profile likelihood, given appropriate settings [38].

**SuperBayeS-v2.0** is interfaced with the following programs: **SOFTSUSY 3.3.10** [45, 46] for SUSY spectrum calculations; **MICROMEAS 2.4** [47, 48] to compute the abundance of dark matter; **DARKSUSY 5.0.5** [49, 50] for the computation of  $\sigma_{\chi_N}^{\text{SI}}$ , the spin-independent

Standard Model			Hadronic		
$m_t$ [GeV]	$172.99 \pm 0.91$	[56]	$f_{T_u}$	$0.0457 \pm 0.0065$	[57]
$m_b(m_b)^{\overline{MS}}$ [GeV]	$4.18 \pm 0.03$	[58]	$f_{T_d}$	$0.0457 \pm 0.0065$	[57]
$[\alpha_{EM}(m_Z)^{\overline{MS}}]^{-1}$	$127.944 \pm 0.014$	[58]	$f_{T_s}$	$0.043 \pm 0.011$	[59]
$\alpha_S(m_Z)^{\overline{MS}}$	$0.1185 \pm 0.0006$	[58]	$\Delta_u$	$0.787 \pm 0.158$	[60]
Astrophysical			$\Delta_d$	$-0.319 \pm 0.066$	[60]
$\rho_{loc}$ [GeV cm $^{-3}$ ]	$0.4 \pm 0.1$	[61]	$\Delta_s$	$-0.020 \pm 0.011$	[60]
$v_\odot$ [km s $^{-1}$ ]	$230.0 \pm 30.0$	[61]			

**Table 3.** Standard Model, astrophysical and hadronic parameters used in the analysis. The standard deviation gives the scale of the uncertainty in each (although this is not used in the analysis except in the case of  $m_t$ ). The astrophysical quantities are the local dark matter density,  $\rho_{loc}$ , and the velocity of the Sun relative to the Galactic rest frame  $v_\odot$ . For the dark matter velocity distribution the so-called Maxwellian distribution is used. The velocity dispersion is assumed to be  $v_d = \sqrt{3/2} v_\odot$ . The hadronic matrix elements,  $f_{T_u}$ ,  $f_{T_d}$  and  $f_{T_s}$  parameterise the contributions of the light quarks to the proton composition for spin-independent cross-section while  $\Delta_u$ ,  $\Delta_d$  and  $\Delta_s$  the contributions of the light quarks to the total proton spin for the spin-dependent neutralino-proton scattering cross-section.

(SI)  $\tilde{\chi}_1^0$ -nucleon scattering cross-section, and  $\sigma_{\chi p}^{SD}$ , the spin-dependent (SD)  $\tilde{\chi}_1^0$ -proton scattering cross-section; SUPERISO 3.0 [51, 52] to compute flavour-physics observables; and SUSYBSG 1.6 [53, 54] for the determination of  $BR(B \rightarrow X_s \gamma)$ . For the computation of the electroweak precision observables described below, the complete one-loop corrections and the available MSSM two-loop corrections have been implemented, as have the full Standard Model results [55].

Uncertainties in the measured value of the top quark mass,  $m_t = 172.99 \pm 0.91 \text{ GeV}$  [56], can have a significant impact on the results of SUSY analyses. Therefore  $m_t$  is included as a nuisance parameter in the scans, with a Gaussian prior, in addition to the model parameters described above. Uncertainties in other Standard Model parameters, as well as astrophysical and nuclear physics quantities that enter the likelihood for the direct-detection experiments (described in section 4), have a very limited impact on the scan. Thus to limit the dimensionality of the parameter space considered, these other nuisance parameters are fixed in the analysis. The values used for all Standard Model, astrophysical and hadronic parameters are shown in table 3.

### 3.2 Experimental constraints in the initial likelihood scan

A set of existing experimental constraints is used in the initial likelihood scan over the 5D pMSSM to select the models in which to consider the impact of the ATLAS SUSY searches. They are implemented with a joint likelihood function, whose logarithm takes the following form:

$$\ln \mathcal{L}_{\text{Joint}} = \ln \mathcal{L}_{\text{EW}} + \ln \mathcal{L}_{\text{B}} + \ln \mathcal{L}_{\Omega_\chi h^2} + \ln \mathcal{L}_{\text{DD}} + \ln \mathcal{L}_{\text{Higgs}} + \ln \mathcal{L}_{\text{LEP-}\tilde{\chi}_1^\pm}, \quad (3.3)$$



Observable	Mean value	Standard deviation		Ref.
		Experimental	Theoretical	
$m_W$ [GeV]	80.385	0.015	0.01	[62]
$\sin^2\theta_{\text{eff}}^{\text{lept}}$	0.23153	0.00016	0.00010	[63]
$\Gamma_Z$ [GeV]	2.4952	0.0023	0.001	[64]
$\Gamma_Z^{\text{inv}}$ [GeV]	0.499	0.0015	0.001	[62]
$\sigma_{\text{had}}^0$ [nb]	41.540	0.037	—	[64]
$R_\ell^0$	20.767	0.025	—	[64]
$R_b^0$	0.21629	0.00066	—	[64]
$R_c^0$	0.1721	0.003	—	[64]
$BR(B \rightarrow X_s \gamma) \times 10^4$	3.55	0.26	0.30	[62]
$\frac{BR(B_u \rightarrow \tau \nu)}{BR(B_u \rightarrow \tau \nu)_{\text{SM}}}$	1.62	0.57	—	[65]
$BR(B_s^0 \rightarrow \mu^+ \mu^-) \times 10^9$	2.9	1.1	0.38	[66]
$\Omega_\chi h^2$	0.1186	0.0031	0.012	[67]
$m_h$ [GeV]	125.36	0.41	2.0	[68]
	Limit			Ref.
$m_\chi$ vs. $\sigma_{\chi N}^{\text{SI}}$	XENON100 2012 ( $224.6 \times 34$ kg days)			[69]
$m_\chi$ vs. $\sigma_{\chi p}^{\text{SD}}$	XENON100 2012 ( $224.6 \times 34$ kg days)			[70]
$m_\chi$ vs. $\sigma_{\chi N}^{\text{SI}}$	LUX 2013 ( $118 \times 85.3$ kg days)			[71]
Chargino mass	LEP2			[62]

**Table 4.** Summary of experimental constraints that are used in the likelihood. Upper part: measured observables, modelled with a Gaussian likelihood with the standard deviation  $(\sigma^2 + \tau^2)^{1/2}$ , where  $\sigma$  is the experimental and  $\tau$  the theoretical uncertainty. Lower part: observables for which only limits currently exist.  $\sigma_{\chi N}^{\text{SI}}$  and  $\sigma_{\chi p}^{\text{SD}}$  denote spin-independent and spin-dependent LSP-nucleon scattering cross-sections respectively. See text for further information about the explicit form of the likelihood function. All the observables are described in section 3.

where  $\mathcal{L}_{\text{EW}}$  represents electroweak precision observables,  $\mathcal{L}_B$   $B$ -physics constraints,  $\mathcal{L}_{\Omega_\chi h^2}$  measurements of the cosmological dark matter relic density,  $\mathcal{L}_{\text{DD}}$  direct dark matter detection constraints,  $\mathcal{L}_{\text{Higgs}}$  the ATLAS measurement of the Higgs boson mass, and  $\mathcal{L}_{\text{LEP-}\tilde{\chi}_1^\pm}$  the LEP2 limit on the chargino mass.

Table 4 shows the set of experimental constraints used in the analysis. Their implementation is summarised below.

The constraints on the electroweak precision observables are obtained from  $Z$ -pole measurements at LEP [64], and include the constraint on the effective electroweak mixing angle for leptons  $\sin^2\theta_{\text{eff}}^{\text{lept}}$ , the total width of the  $Z$  boson  $\Gamma_Z$ , the invisible  $Z$  boson width  $\Gamma_Z^{\text{inv}}$ , the hadronic pole cross-section  $\sigma_{\text{had}}^0$ , as well as the decay width ratios  $R_\ell^0$ ,  $R_b^0$  and  $R_c^0$ . The combined Tevatron and LEP  $W$  boson mass ( $m_W$ ) estimate [62] is also included. The  $B$ -physics

constraints include a number of world averages obtained by the Heavy Flavour Averaging Group, including the branching fraction  $BR(B \rightarrow X_s \gamma)$  and the ratio of the branching fraction of the decay  $B_u \rightarrow \tau \nu$  to its branching fraction predicted in the Standard Model [62]. Finally, the measurement of the rare decay branching fraction  $BR(B_s^0 \rightarrow \mu^+ \mu^-)$  from the LHCb experiment at the LHC is used [66]. At the time of the initial likelihood scan a compatible measurement from CMS [72] was also available. Either of these measurements could have been used without changing the results, and the LHCb value was chosen due to chronological precedence. A combination of the CMS and LHCb measurements was later published [73] after the initial model selection for this work had been performed. The results from the combination are compatible with the LHCb value and would not have a noticeable impact on the final results. The electroweak precision and  $B$ -physics constraints are applied as Gaussian likelihoods with means and standard deviations as indicated in table 4.

For the cosmological constraints the Planck Collaboration's constraint on the dark matter relic abundance is used, as this is the most accurate value available. The constraint is implemented differently depending on the proportion of dark matter attributed to neutralinos. If the neutralino were to make up all of the dark matter in the universe, the result from Planck temperature and lensing data,  $\Omega_\chi h^2 = 0.1186 \pm 0.0031$ , would be applied as a Gaussian likelihood [67]. But here, the neutralino is allowed to be a sub-dominant dark matter component, and the Planck relic density measurement is instead applied as an upper limit. The effective likelihood for the upper limit, taking into account the error, is given by the expression

$$\mathcal{L}_{\Omega_\chi h^2} = \mathcal{L}_0 \int_{\Omega_\chi h^2 / \sigma_{\text{Planck}}}^{\infty} e^{-\frac{1}{2}(x-r_\star)^2} x^{-1} dx, \quad (3.4)$$

as derived in the appendix of ref. [74].  $\mathcal{L}_0$  is an irrelevant normalisation constant,  $r_\star \equiv \mu_{\text{Planck}} / \sigma_{\text{Planck}}$ , and  $\Omega_\chi h^2$  is the predicted relic density of neutralinos as a function of the model parameters. Here  $\mu_{\text{Planck}}$  refers to the value of  $\Omega_\chi h^2$  inferred by the Planck Collaboration and  $\sigma_{\text{Planck}}$  to its uncertainty. Both numbers are given in table 4. A fixed theoretical uncertainty,  $\tau = 0.012$ , is also added in quadrature to the experimental error, in order to account for the numerical uncertainties entering in the calculation of the relic density from the SUSY parameters.

When neutralinos are not the only constituent of dark matter, the rate of events in a direct-detection experiment is proportionally smaller, as the local neutralino density,  $\rho_\chi$ , is now smaller than the total local dark matter density,  $\rho_{\text{DM}}$ . The suppression is given by the factor  $\xi \equiv \rho_\chi / \rho_{\text{DM}}$ . Following ref. [75], the ratio of local neutralino density to total dark matter densities is assumed to be equal to that for the cosmic abundances, thus a scaling ansatz is adopted:

$$\xi \equiv \frac{\rho_\chi}{\rho_{\text{DM}}} = \frac{\Omega_\chi}{\Omega_{\text{DM}}}. \quad (3.5)$$

For  $\Omega_{\text{DM}}$ , the central value measured by the Planck Collaboration,  $\Omega_{\text{DM}} h^2 = 0.1186$ , is used [67].

The direct-detection constraint uses the recent results from XENON100, with 225 live days of data collected between February 2011 and March 2012 with a 34 kg fiducial

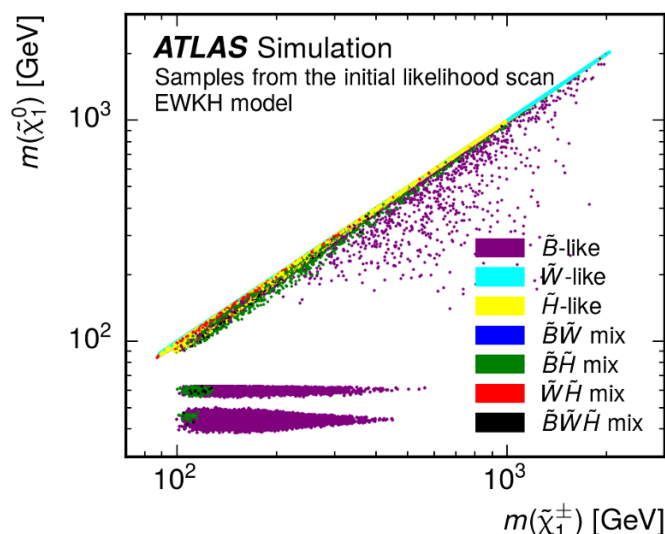
volume [69]. The treatment of XENON100 data is described in detail in ref. [76]. The likelihood function is built as a Poisson distribution for observing  $N$  recoil events when  $N_s(\Theta)$  signal plus  $N_b$  background events are expected. The expected number of background events the XENON100 run is  $N_b = 1.0 \pm 0.2$ , while the collaboration reported  $N = 2$  events observed in the pre-defined signal region. An updated version of the likelihood function described in refs. [76, 77] is used. For the spin-independent cross section, the LUX data from 85.3 live-days with a fiducial volume of 118 kg [71] is used, as this result became available in time to be included in the analysis. The LUX limit was included using the likelihood computed by the LUXCalc package [78]. The likelihood is constructed from a Poisson distribution in which the numbers of observed and background events are 1 and 0.64, respectively. Improved spin-independent [79, 80] and new spin-dependent [81] limits have in the meantime been published by LUX, but have not been included in this work as they became available as this analysis was being finalized. Such limits are not expected to lead to significantly different results for this analysis.

For the implementation of the Higgs boson likelihood the most recent measurement by the ATLAS experiment of the mass of the Higgs boson is used,  $m_h = 125.36 \pm 0.37 \pm 0.18 \text{ GeV}$ , where the first error is statistical and the second error is systematic [68]. This is fully compatible with the most recent CMS measurement [82]. A theoretical error of 2 GeV [83] is added in quadrature to the quoted uncertainties. The observed upper limit of 0.23 on the branching fraction for Higgs boson decays into invisible particles [84] (e.g.  $\nu, \tilde{\chi}_1^0$ ) is not included. Including this bound would exclude at the 95% confidence level (CL) 5% of models surviving the initial likelihood scan, and 8% of those remaining after the electroweak SUSY analysis constraints have been applied.

Finally, the likelihood associated with the  $m(\tilde{\chi}_1^\pm)$  constraint from LEP2 data is taken from equation (3.5) of ref. [85], where an experimental lower bound of 92.4 GeV [62] and a theoretical uncertainty of 5% from the SOFTSUSY 3.3.10 prediction of the spectrum is assumed.

### 3.3 Phenomenology of the LSP

As mentioned in section 3.1, the results of the likelihood scan are used to select models upon which to consider the sensitivity of the electroweak SUSY searches. Figure 1 displays the LSP composition of those models within the 95% CL 2D contours, and their distribution in the  $\tilde{\chi}_1^0$  versus  $\tilde{\chi}_1^\pm$  mass plane. The colours encode the  $\tilde{\chi}_1^0$  composition of the models. Three distinct regions are seen, which correspond to different mechanisms to enhance the annihilation cross-section and thus avoid having a cosmological relic density larger than observed. There is the so-called  $Z$ -funnel region, where the LSP mass is close to 45 GeV and it is mostly bino-like. In this case, the annihilation rate is proportional to the higgsino fraction of the  $\tilde{\chi}_1^0$ . The region centred on  $m(\tilde{\chi}_1^0) \sim 60 \text{ GeV}$  corresponds to a  $\tilde{\chi}_1^0$  that annihilates through a mechanism similar to that in the  $Z$ -funnel but involving the lightest Higgs boson instead. This is the so-called  $h$ -funnel, and the annihilation rate is proportional to the higgsino fraction as well as the combined bino and wino fraction. In each funnel, the  $\tilde{\chi}_1^0$  annihilation rate is enhanced due to a pole in the propagator ( $2m(\tilde{\chi}_1^0) \sim m_Z$  or  $m_h$ , respectively) and thus the Planck constraint can be satisfied. Finally, there is a



**Figure 1.** Scatter plot of models in the  $m(\tilde{\chi}_1^0)$  vs.  $m(\tilde{\chi}_1^\pm)$  plane with the colour encoding which category of  $\tilde{\chi}_1^0$  composition the model belongs to. The  $\tilde{\chi}_1^0$  is defined as bino-like ( $\tilde{B}$ -like), wino-like ( $\tilde{W}$ -like) or higgsino-like ( $\tilde{H}$ -like) if the relevant fraction is at least 80%. A mixed  $\tilde{\chi}_1^0$  has at least 20% of each denoted component and < 20% of any other component. The models considered are all within the 95% confidence region found using the initial likelihood scan.

compressed region, where  $m(\tilde{\chi}_1^0) \approx m(\tilde{\chi}_1^\pm)$ . Here, the LSP composition is less constrained — in particular, higgsino-like and wino-like states are likely, as well as wino-higgsino mixed states. Some model points with  $m(\tilde{\chi}_1^0) \gtrsim 200\text{GeV}$  have a non-compressed spectrum and a nearly pure bino-like LSP. These correspond to the so-called *A*-funnel region, where dark matter annihilates through the pseudoscalar Higgs boson pole.

#### 4 Signal simulation and evaluation of ATLAS constraints

Constraints from ATLAS SUSY searches are imposed on the 570 599 models generated in the initial likelihood scan by generating and simulating events from a subset of these models. The models are split into three categories: those considered to be already excluded by pre-existing constraints and having a  $\tilde{\chi}_1^0$  lighter than 1TeV (108 740 models); those where the considered analyses are assumed to be insensitive without performing a detailed analysis (134 624 models); and those that are simulated to assess the impact of the searches in table 1 (326 951 models).

The pre-existing constraint defining the first category of models is the LEP2 limit on the mass of the lightest chargino,  $m(\tilde{\chi}_1^\pm) > 92.4\text{GeV}$ . The second category, consisting of models for which the considered searches are not expected to have any sensitivity, is defined by estimating the total production cross-section for SUSY particle production, using PROSPINO2 [86–90]. The searches are not optimised for detecting the decay products of sparticles very close in mass to the LSP, and therefore a process  $pp \rightarrow \tilde{\chi}_i \tilde{\chi}_j$  is only included in the cross-section calculation if  $\Delta m(\tilde{\chi}_i, \text{LSP})$  or  $\Delta m(\tilde{\chi}_j, \text{LSP})$  is greater than

5 GeV. Models with a total cross-section for all considered electroweak SUSY production processes below 0.25 fb are placed in the second category and not processed further at this stage. They are, however, included as unexcluded models in section 5.

The remaining 326 951 models, in the third category, are simulated at particle level using MADGRAPH 1.5.12 [91] with the CTEQ 6L1 parton density function set [92] and PYTHIA 6.427 [93] with the AUET2B [94] set of tuned parameters. MADGRAPH is used to generate the initial pair of sparticles and up to one additional parton, while PYTHIA is used for all sparticle decays and parton showering. TAUOLA [95] and PHOTOS [96] are used to handle the decays of  $\tau$ -leptons and the final-state radiation of photons, respectively. Expected signal region yields are calculated for each of the four considered analyses using these simulated events.

To avoid the computational cost of processing every model with the ATLAS detector simulation, a “calibration procedure” is used to extract  $CL_s$  values for the models using the particle-level signal region yields described above. Of the 326 951 simulated models, a random sample of 500 models was selected and processed using a fast GEANT4-based [97] simulation of the ATLAS detector, with a parameterisation of the performance of the ATLAS electromagnetic and hadronic calorimeters [98] and full event reconstruction. The selected models follow approximately the initial likelihood scan and thus span the relevant parameter space. The number of events generated for each of these models corresponds to approximately four times the recorded integrated luminosity collected at  $\sqrt{s} = 8$  TeV, i.e.  $80 \text{ fb}^{-1}$ . For these simulated models, signal cross-sections are calculated at next-to-leading (NLO) order in the strong coupling constant using PROSPINO2 [88]. These cross-sections are in agreement with the NLO calculations matched to resummation at the next-to-leading-logarithmic accuracy (NLO+NLL) within  $\sim 2\%$  [99–101]. The nominal cross-section and the uncertainty are taken from an envelope of cross-section predictions using different parton distribution function sets and factorisation and renormalisation scales, as described in ref. [102].

These 500 models are then analysed using the full statistical framework [103] of the original ATLAS electroweak SUSY analyses and a  $CL_s$  value is calculated for each of them. One difference with respect to the published analyses is that signal regions that would normally be statistically combined in the likelihood fit are now treated as separate signal regions, and  $CL_s$  values are calculated for each region. Similarly, for binned signal regions each bin is treated separately. The results from the 500 models are used to fit a “calibration function” between the particle-level yields and the  $CL_s$  values for each signal region. This accounts for the SM background prediction in each signal region, together with the observed data. There is one remaining free parameter, which roughly corresponds to the average selection efficiency for SUSY events that pass the particle-level selection. Only those signal regions where the average efficiency could be determined with a statistical precision of better than 20% are considered in the final analysis. In addition, it is required that at least one of the 500 models is excluded, with expected and observed  $CL_s < 0.05$ . Of the original 44 signal regions, 25 pass these requirements. The 19 rejected signal regions typically have a low acceptance for the EWKH models, due to either very stringent kinematic criteria, or a requirement for  $\tau_{\text{had}}$  candidates, which have a low yield in the EWKH models considered, due to

the very high mass of the stau. The real selection efficiency varies from model to model, and the calibration procedure therefore can only give accurate results when averaged over many models. No additional systematic uncertainty for model-to-model variations is applied.

This simplified method provides an efficient way to calculate the impact of the electroweak searches and the calibration functions are used to extract  $CL_s$  values for all 326 951 considered models. The best constraints on any signal model would be obtained from a statistical combination of all relevant signal regions; however, this is not possible with this simplified approach so instead a conservative approach is used where the  $CL_s$  value is taken from the signal region with the smallest expected  $CL_s$  value.

## 5 Impact of the ATLAS electroweak SUSY searches

In this section the impact of the ATLAS electroweak SUSY searches is discussed in terms of 1D and 2D distributions. The models considered for each distribution are those within the 95% confidence region according to the initial likelihood scan outlined in section 3. There are 438 589 and 472 933 such models in the 1D and 2D case, respectively.

A model is considered to be excluded by the ATLAS electroweak SUSY searches if the observed  $CL_s$  value, calculated as explained in section 4, is less than 0.05. For the 1D distributions in this section, stacked plots are used to indicate the contributions of the  $2\ell$ ,  $3\ell$  and  $4\ell$  searches. The  $2\tau$  search is found to be insensitive, relative to the other searches, due to the lack of light staus in these models. Signal regions of the  $3\ell$  and  $4\ell$  searches that require  $\tau_{\text{had}}$  candidates are similarly insensitive to these models. If more than one search can exclude a model, the one with the smallest expected  $CL_s$  value is chosen, following the procedure in section 4. For the 2D plots the colours represent the fraction of models which are excluded by ATLAS data at 95% CL. In all of the distributions the fractions displayed correspond to the proportion of models excluded for a given bin in the parameter space.

Of the 472 933 models within the two-dimensional 95% CL bound before the ATLAS electroweak SUSY analyses are considered, approximately 3% are excluded by the searches considered (listed in table 1). The  $3\ell$  search is the most powerful of the four analyses across these models, having the signal region with the lowest expected  $CL_s$  for 63.3% of the excluded models. The high sensitivity of this search is largely due to a signal region that is binned in kinematic quantities such as the dilepton invariant mass and  $E_T^{\text{miss}}$  (the signal region is called SR0 $\tau a$  in ref. [34]). The 20 bins of SR0 $\tau a$  are treated here as 20 individual signal regions, the most powerful of which (for these models) is bin 16, requiring a  $Z$  boson candidate and stringent lower limits on the transverse mass ( $m_T$ ) and  $E_T^{\text{miss}}$ . The  $2\ell$  and  $4\ell$  searches exclude smaller fractions of models, although they have areas of unique sensitivity, as discussed below.

### 5.1 Impact on the electroweakino masses

The fractions of models excluded as a function of  $m(\tilde{\chi}_1^0)$ ,  $m(\tilde{\chi}_1^\pm)$ , and  $m(\tilde{\chi}_2^0)$  are shown as 2D and 1D distributions in figures 2 and 3, respectively. Areas where no models survive the initial likelihood scan are left white in figure 2 and figure 3. For example, chargino masses below 100 GeV are strongly disfavoured due to the LEP2 constraint, which also impacts the



range of  $\tilde{\chi}_2^0$  masses that can be considered. The  $Z$ - and  $h$ -funnel regions are also clearly visible in both figures 2(a) and 3(a).

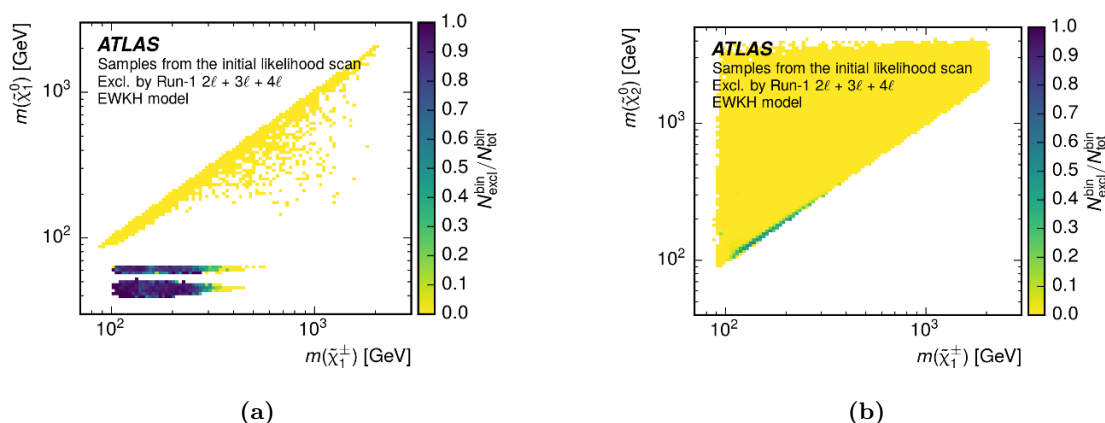
These results show that the considered searches effectively constrain the  $Z$ - and  $h$ -funnel regions of the parameter space, with the greatest impact when  $m(\tilde{\chi}_1^\pm) \lesssim 300\text{GeV}$ . In this scenario the leptons produced in the decay of the produced electroweakinos to the LSP have a large signal acceptance, and the production cross-section of wino- and higgsino-like particles can reach  $\mathcal{O}(\text{pb})$  with these masses. The searches have a negligible impact in the compressed region where  $m(\tilde{\chi}_1^0) \approx m(\tilde{\chi}_1^\pm)$ , since the reconstruction efficiency of low- $p_T$  leptons ( $p_T \lesssim 5\text{GeV}$ ) is small.

Overall, the results are dominated by the  $3\ell$  search, as explained above. The  $4\ell$  search is uniquely sensitive to a small fraction of models in a particular region of the parameter space where all of the electroweakinos have masses smaller than approximately  $300\text{GeV}$ . These models also have a particular pattern of wino/higgsino mixing that especially favours the SR0Z signal region, which requires a  $Z$  candidate and significant  $E_T^{\text{miss}}$  [35]. The signal process  $pp \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_3^0 \rightarrow Z \tilde{\chi}_1^0 Z \tilde{\chi}_1^0$  was already considered in the  $4\ell$  search paper as a simplified model; however, the relatively light ( $m \lesssim 300\text{GeV}$ ) wino-like  $\tilde{\chi}_4^0$  and  $\tilde{\chi}_2^\pm$  particles supplement the search sensitivity via long cascades such as  $\tilde{\chi}_2^+ \tilde{\chi}_2^- \rightarrow (Z \tilde{\chi}_1^+)(W^- \tilde{\chi}_2^0) \rightarrow (ZW^+ \tilde{\chi}_1^0)(W^- Z \tilde{\chi}_1^0)$ . The  $2\ell$  search is mainly used to exclude models with extremely light higgsino-like particles ( $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) \sim 100\text{--}130\text{GeV}$ ), with a bino-like LSP in the  $Z$ - or  $h$ -funnel region. The exclusion power arises mostly from the signal region SR-WWa, which is optimised for processes such as  $pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow (W^{+*} \tilde{\chi}_1^0)(W^{-*} \tilde{\chi}_1^0)$  where  $m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) < m_W$  [30]. The wino-like electroweakinos are usually significantly more massive ( $m(\tilde{\chi}_4^0, \tilde{\chi}_2^\pm) \gtrsim 300\text{GeV}$ ), such that the search is mainly sensitive to  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ ,  $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$  and  $\tilde{\chi}_3^0 \tilde{\chi}_1^\pm$  pair production.

Comparing figures 2(b) and 3(c) shows that these searches are in general only sensitive to models where the  $\tilde{\chi}_2^0$  mass is smaller than about  $300\text{GeV}$ . The proportion of excluded models approaches 30% in the best case, for  $m(\tilde{\chi}_2^0) \approx 120\text{GeV}$ . This subset of models corresponds most closely to the canonical signature targeted by the  $2\ell$ ,  $3\ell$  and  $4\ell$  searches, where wino- or higgsino-like particles decay to a bino-like LSP and either a  $W$  or  $Z$  boson (which may be off-shell). These searches are expected to be less sensitive in the case where the  $\tilde{\chi}_2^0$  and  $\tilde{\chi}_1^\pm$  masses are not degenerate, as seen in figure 2(b). Then, even if the  $\tilde{\chi}_1^\pm$  is accessible, typically this implies that it and the LSP are both mostly wino-like, with a very small mass difference that prevents detection by the considered analyses. The ATLAS search for disappearing tracks [36] targets this kind of signature, in the case where the mass difference is small enough that the  $\tilde{\chi}_1^\pm$  can traverse a significant portion of the detector before it decays ( $\Delta m \lesssim 200\text{MeV}$ ). A full consideration of this search would lead to further constraints in this part of the parameter space as shown in ref. [26].

## 5.2 Impact on the EWKH model parameters

Figures 4 and 5 display the fraction of models excluded for the five EWKH parameters:  $M_1$ ,  $M_2$ ,  $\mu$ ,  $m_A$  and  $\tan\beta$ . As before, regions of the parameter space are visible where no models are allowed. For example, there are no models with  $M_2$  or  $|\mu|$  less than  $80\text{GeV}$  due to the LEP2 constraint on the  $\tilde{\chi}_1^\pm$  mass. The measured value of  $BR(B_s^0 \rightarrow \mu^+ \mu^-)$  is



**Figure 2.** The bin-by-bin fraction of models excluded as a 2D function of sparticle masses. The colour encodes the fraction of models excluded. The models considered are all within the 2D 95% confidence region found using the initial likelihood scan. No such models are in the white regions, and therefore the coloured bins indicate the 95% CL contours for the initial likelihood scan.

compatible with the Standard Model prediction, disfavouring the region with  $m_A \lesssim 500\text{GeV}$  in figure 5(d) as contributions to that process typically scale as  $\sim \tan^6 \beta / m_A^2$ . Finally, values of  $\tan \beta \gtrsim 10$  (figure 5(e)) are strongly favoured because the tree-level contribution to the Higgs boson mass is maximised.

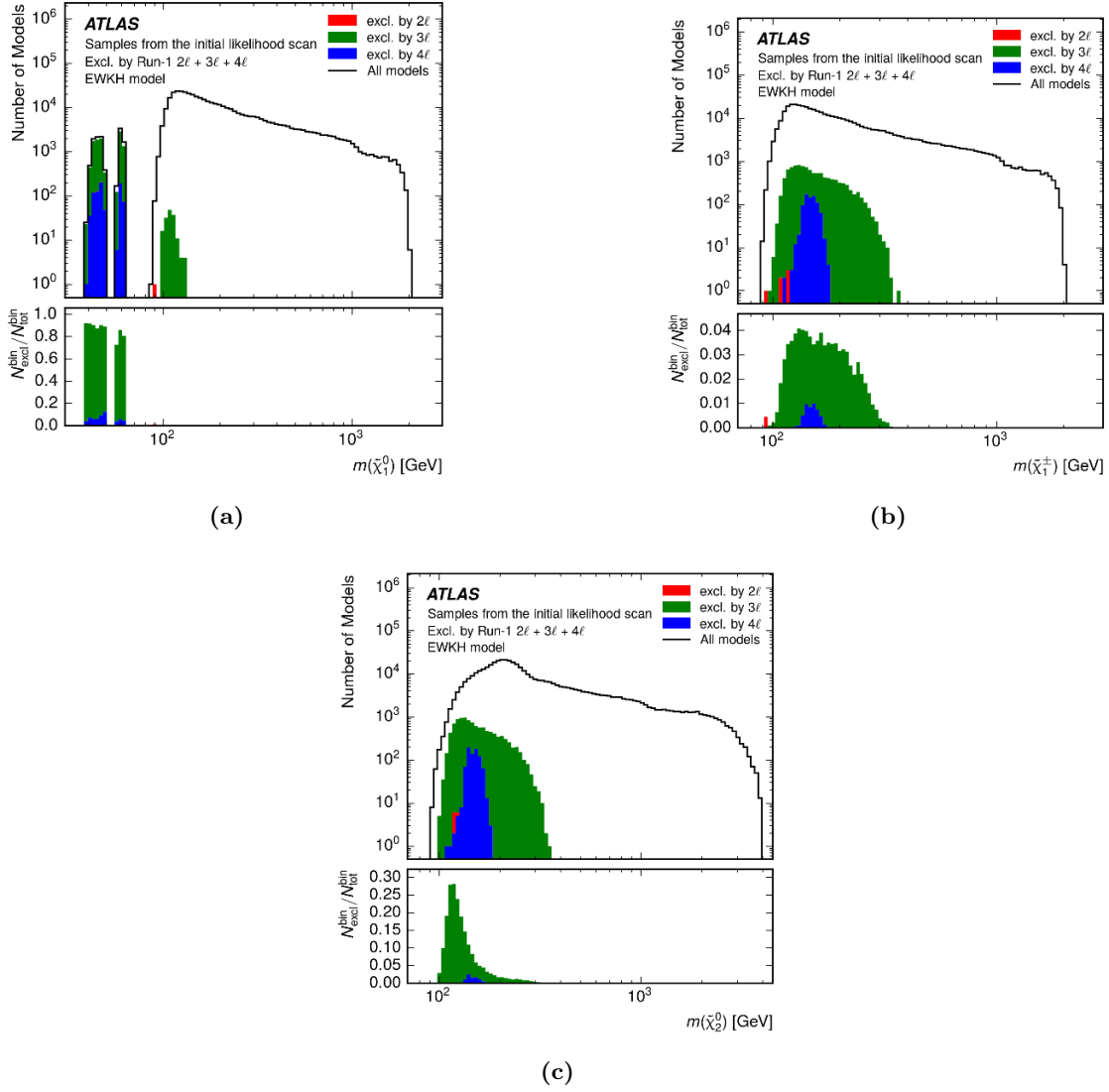
As seen in figures 4 and 5(a)–5(c), the considered searches have the strongest impact when  $|M_1|$ ,  $M_2$  and  $|\mu|$  are all small ( $\ll 1\text{TeV}$ ), where the SUSY particle production cross-section is large. The searches have the strongest impact where the  $\tilde{\chi}_1^0$  is light and bino-like; approximately 86% of models with  $|M_1| < 85\text{GeV}$  are excluded, which corresponds to the region  $m(\tilde{\chi}_1^0) < 65\text{GeV}$  in figure 3. The impact on  $M_2$  and  $\mu$  is less severe, where the excluded fraction peaks at about 4%. In the case of  $M_2$ , a small number of models with  $M_2 > 1\text{TeV}$  are excluded, corresponding to models with a light higgsino spectrum and a bino-like LSP.

The considered searches can only provide indirect constraints on the remaining model parameters,  $m_A$  and  $\tan \beta$ . Therefore, the features in figures 5(d) and 5(e) are driven by the properties of models with a low-mass LSP in the  $Z$ - or  $h$ -funnel. Although the pseudoscalar boson does not enter directly into the phenomenology of the considered electroweak searches, the proportion of excluded models is greatest for values of  $m_A$  below  $1\text{TeV}$ , while the excluded models span a wide range of  $\tan \beta$  between about 20 and 50.

### 5.3 Impact on dark matter observables

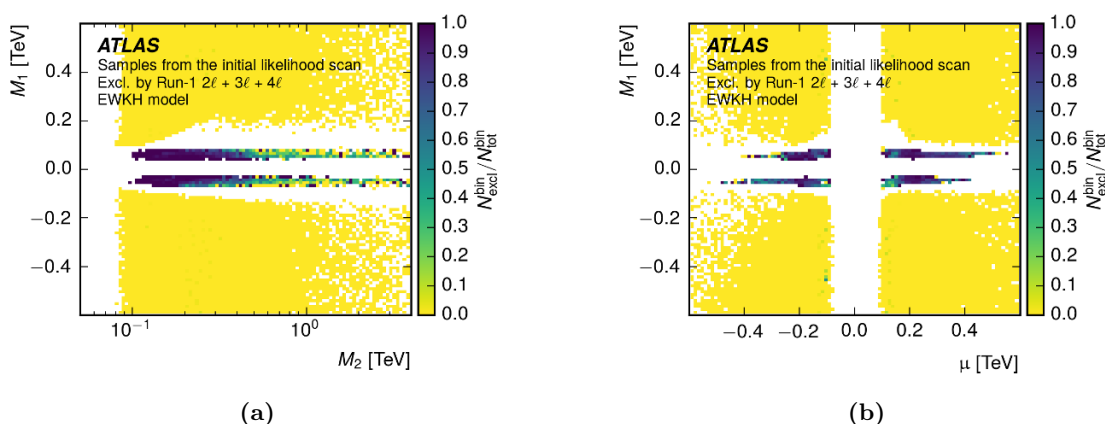
Finally, the impact of the considered electroweak searches in several 2D parameter spaces relevant to dark matter phenomenology is shown in figure 6. Figure 6(a) shows the fraction of models excluded in the  $\tilde{\chi}_1^0$  relic abundance versus  $\tilde{\chi}_1^0$  mass plane. The  $Z$ - and  $h$ -funnel regions can again be clearly seen. The exclusion power of the considered searches depends only weakly upon the relic density, which can be as small as  $\sim 10^{-3}$  depending on the higgsino component of the LSP and thus the efficiency of the  $s$ -channel annihilation.





**Figure 3.** The number of models sampled by the initial likelihood scan, and the stacked bin-by-bin number of models excluded by the Run 1 ATLAS SUSY searches as a 1D function of  $m(\tilde{\chi}_1^0)$ ,  $m(\tilde{\chi}_1^\pm)$ , and  $m(\tilde{\chi}_2^0)$ . The lower part of each figure shows the fraction of models excluded by the Run 1 ATLAS SUSY searches. The red bins indicates the fraction that is excluded by a  $2\ell$  SR, the green by a  $3\ell$  SR, and blue by a  $4\ell$  SR. The models considered are all within the 1D 95% confidence interval found using the initial likelihood scan.

The region at higher LSP mass corresponds to the region where the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_1^0$  are close in mass (cf. figure 1). Efficient coannihilation between these states (and the  $\tilde{\chi}_2^0$ , if relevant) reduces the relic density with respect to a pure bino-like particle. Pure higgsino-like states with  $m(\tilde{\chi}_1^0) \sim 1\text{TeV}$  and pure wino-like states with  $m(\tilde{\chi}_1^0) \sim 2\text{TeV}$  saturate the relic density. Below these masses, mixed states can give rise to the full range of relic densities illustrated in the plot. Finally, the  $A$ -funnel region can be seen in the models with  $m(\tilde{\chi}_1^0) \gtrsim 200\text{GeV}$  away from the compressed spectrum strip in figure 2(a). In this region the  $\tilde{\chi}_1^0$  is mostly bino-like. As discussed above, the considered searches have a negligible impact on these regions.

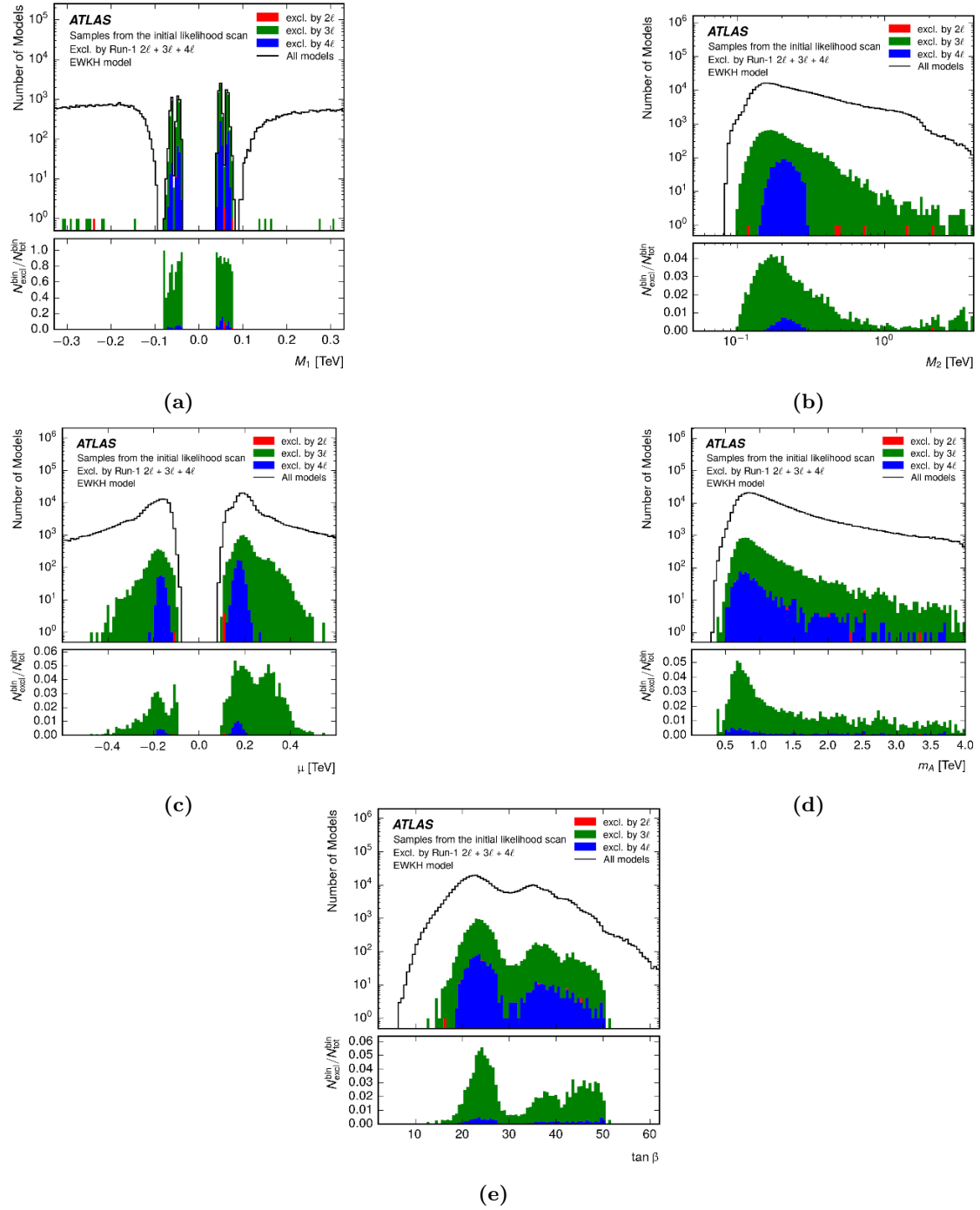


**Figure 4.** The bin-by-bin fraction of models excluded as a 2D function of model parameters. The colour encodes the fraction of models excluded. The models considered are all within the 2D 95% confidence region found using the initial likelihood scan. No such models are in the white regions, and therefore the coloured bins indicate the 95% CL contours for the initial likelihood scan. The plots are truncated in  $|M_1|$  and  $|\mu|$  to highlight the region of ATLAS electroweak SUSY sensitivity.

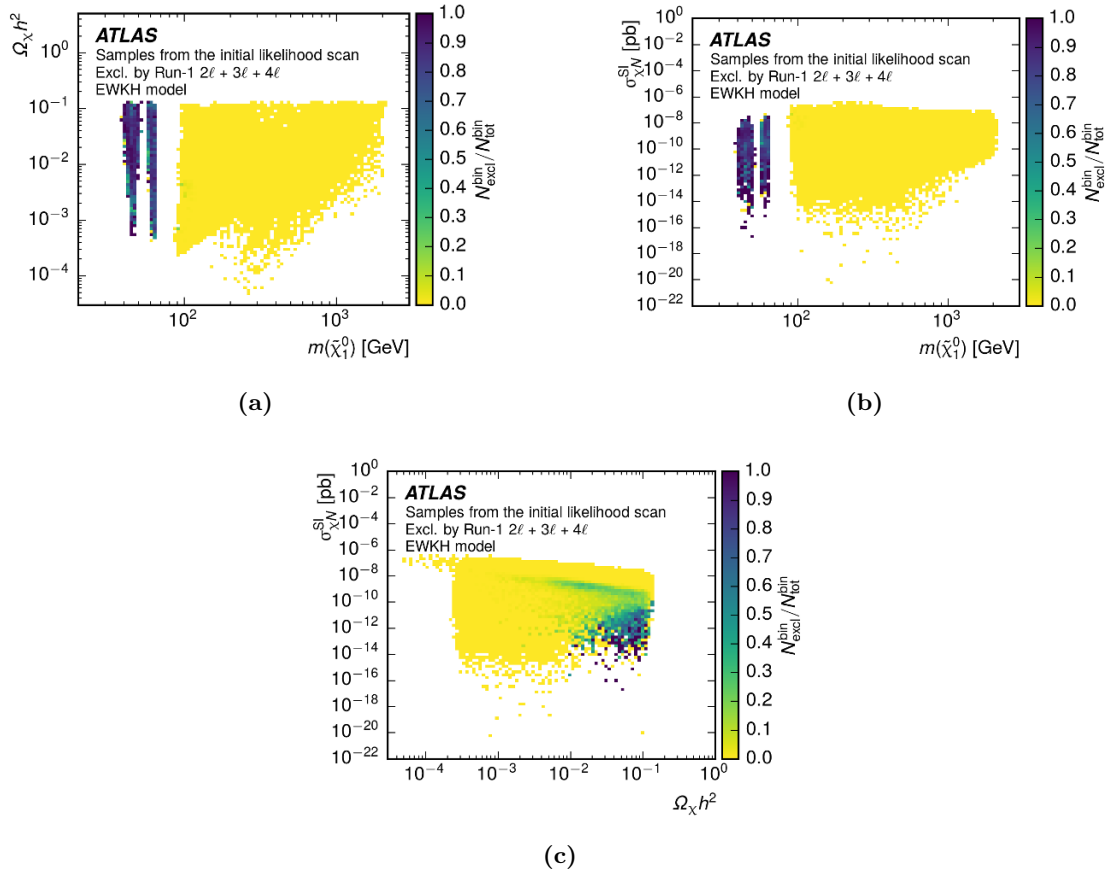
Figure 6(b) shows the SI  $\tilde{\chi}_1^0$ -proton scattering cross-section versus the  $\tilde{\chi}_1^0$  mass. This shows that each of the three regions with different dark matter annihilation mechanisms spans a large cross-section range. Large values of the cross-section are not penalised in the likelihood scan because the scaling factor  $\xi$  given in Equation (3.5) reduces the predicted number of recoil events, weakening both the XENON100 and LUX constraints. The largest cross-sections are achieved when the  $\tilde{\chi}_1^0$  acquires some higgsino component, whereas cross-sections are suppressed when the  $\tilde{\chi}_1^0$  has an increased bino or wino component in the low/intermediate  $\tilde{\chi}_1^0$  mass regions. Very low values of  $\sigma_{\chi N}^{\text{SI}} \lesssim 10^{-16}$  pb are rare, but occur in some models due to cancellations between the contributions from the two neutral CP-even Higgs bosons. The SUSY searches considered here exclude a large portion of the parameter space with  $m(\tilde{\chi}_1^0) \lesssim 65\text{GeV}$ , including at smaller scattering cross-sections where current and future tonne-scale underground dark matter direct-detection experiments will have less sensitivity.

Figure 6(c) shows the ATLAS constraints in a plane of the SI  $\tilde{\chi}_1^0$ -proton cross-section versus the  $\tilde{\chi}_1^0$  relic density. Since this study assumes that the local  $\tilde{\chi}_1^0$  density scales with the cosmological abundance, the XENON100 and LUX limits are shifted towards larger SI cross-section values for models with a relic density smaller than the value measured by Planck. This translates into a negative correlation for large values of the SI scattering cross-section ( $\gtrsim 10^{-8}$  pb).

For the smallest values of  $\Omega_\chi h^2$  ( $\sim 10^{-4}$ ) the most favoured region of parameter space is a narrow band stretching along the currently largest allowed SI cross-section values of about  $10^{-1}$  pb. In this region, the low relic density is achieved by models that sit on the  $A$ -funnel resonance. The  $\tilde{\chi}_1^0$  for these models is mostly bino but with a sizeable higgsino content which explains the large SI cross-section. This large SI cross-section also puts these models within reach of future direct-detection searches. For larger relic densities, the SI



**Figure 5.** The number of models sampled by the initial likelihood scan, and the stacked bin-by-bin number of models excluded by the Run 1 ATLAS SUSY searches as a 1D function of the EWKH model parameters. The lower part of each figure shows the fraction of models excluded by the Run 1 ATLAS SUSY searches. The red bins indicates the fraction that is excluded by a  $2\ell$  SR, the green by a  $3\ell$  SR, and blue by a  $4\ell$  SR. The models considered are all within the 1D 95% confidence interval found using the initial likelihood scan. The plots are truncated in  $|M_1|$  and  $|\mu|$  to highlight the region of ATLAS electroweak SUSY sensitivity.



**Figure 6.** The bin-by-bin fraction of models excluded as a 2D function of the dark matter observables. The colour encodes the fraction of models excluded. The models considered are all within the 2D 95% confidence region found using the initial likelihood scan. No such models are in the white regions, and therefore the coloured bins indicate the 95% CL contours for the initial likelihood scan.

cross-section is small as long as the higgsino admixture is small, but, in the case where the  $\tilde{\chi}_1^0$  becomes higgsino-like (wino-like), annihilation is still efficient provided the higgsino-like (wino-like)  $\tilde{\chi}_1^0$  has a mass  $m(\tilde{\chi}_1^0) \lesssim 1(2)\text{TeV}$ . In this scenario the relic abundance is low, corresponding to the region  $10^{-4} \lesssim \Omega_\chi h^2 \lesssim 10^{-1}$ . Finally, when the  $\tilde{\chi}_1^0$  is either bino-like (with a mass of  $\sim 50\text{GeV}$  or a few hundred GeV), wino-like (with a mass of about  $2\text{TeV}$ ) or higgsino-like (with a mass of about  $1\text{TeV}$ ) then the relic density matches the measurement from the Planck Collaboration. In these cases the SI cross-section reaches lower values because of the greater purity of the  $\tilde{\chi}_1^0$ .

The impact of the electroweak SUSY searches is stronger for the region of the parameter space where  $10^{-2} \lesssim \Omega_\chi h^2 \lesssim 10^{-1}$  and the SI cross-section is low. There is also a mild impact for larger SI cross-sections ( $10^{-10}$ – $10^{-8}$  pb) when the relic density extends down to  $\Omega_\chi h^2 \sim 10^{-3}$ .

Taken together, these results show that direct searches for the electroweak production of SUSY particles with the ATLAS experiment have a significant impact on the phe-

nomenologically relevant  $Z$ - and  $h$ -funnel regions in the pMSSM, without relying on the production of squarks and gluinos. The exclusions weaken if  $m(\tilde{\chi}_1^\pm) > 300\text{GeV}$ , which motivates further study with Run-2 data collected at  $\sqrt{s} = 13\text{TeV}$ . The considered searches have limited sensitivity in regions of the parameter space that favour  $\tilde{\chi}_1^0\text{-}\tilde{\chi}_1^\pm$  coannihilation and the  $A$ -funnel, although parts of these regions could be explored using other search channels not considered here. The impact of the considered searches is complementary to other constraints, and they probe regions of the parameter space that are difficult to reach with direct-detection dark matter experiments.

## 6 Conclusions

The ATLAS Collaboration performed a set of dedicated searches for electroweak SUSY particle production during the first run of the LHC, using  $pp$  collisions with centre-of-mass energy of  $8\text{TeV}$  and an integrated luminosity of  $20.3\text{fb}^{-1}$ . In this work these searches are interpreted in a five-dimensional realisation of the pMSSM called EWKH. This effective model parameterises the relevant dark matter phenomenology and defines the Higgs sector at tree level of the whole pMSSM.

The parameter space of the theory was initially sampled using a likelihood-driven method. The combined likelihood contains terms for previous collider searches, electroweak precision measurements, flavour physics results, the dark matter relic density and direct dark matter searches, as well as the Higgs boson mass. The dimensionality of the initial likelihood scan was reduced to one or two parameters by maximising the likelihood function over the remaining parameters. This produced 472 933 models within the 2D 95% confidence-level region.

Constraints from ATLAS searches for electroweak SUSY particle production in events with two, three and four charged leptons were then applied by taking the  $\text{CL}_s$  value of the signal region with the best expected sensitivity for each model. Models with  $\text{CL}_s < 0.05$  were considered to be excluded at 95% confidence level. Due to the number of models involved, a new method for estimating the  $\text{CL}_s$  values of different signal regions was developed, which uses only generator-level information in addition to a calibration sample of 500 models that were passed through the full ATLAS detector simulation. The fraction of models excluded as a function of model parameters and masses was then studied.

The dark matter relic density measurement from the Planck Collaboration allows only four regions of parameter space. These correspond to three mechanisms that achieve a high enough dark matter annihilation cross-section. These regions are: the  $Z$ -funnel with  $m(\tilde{\chi}_1^0) \approx 45\text{GeV}$ ; the  $h$ -funnel with  $m(\tilde{\chi}_1^0) \approx 60\text{GeV}$ ; the coannihilation region with  $m(\tilde{\chi}_1^0) \approx m(\tilde{\chi}_1^\pm)$  which extends up to  $m(\tilde{\chi}_1^0) \approx 2\text{TeV}$ ; and the  $A$ -funnel with  $0.2 \lesssim m(\tilde{\chi}_1^0) \lesssim 2\text{TeV}$ . The considered searches exclude 86% of the models in the  $Z$ - and  $h$ -funnel regions ( $m(\tilde{\chi}_1^0) < 65\text{GeV}$ ) while having negligible sensitivity to the coannihilation and  $A$ -funnel regions. The mass spectrum in the coannihilation region is, by definition, compressed, and any leptons produced in the decays of these particles are too soft for the considered searches. It is possible that an existing search, not considered here, for events with a disappearing track would be sensitive to the portion of this region where the mass splitting is  $\lesssim 200\text{MeV}$ , leading to a metastable chargino that would decay in the detector. In addition,

it has been shown that ATLAS searches for squark and gluino production can constrain this region of parameter space, if strongly interacting sparticles are accessible at the LHC. Similarly, in the absence of strong production the  $A$ -funnel region is inaccessible because the electroweakinos are too heavy to be detectable with current data. In all, values of  $|M_1|$  below 100GeV are strongly constrained by the considered searches, while the constraints on  $M_2$ ,  $\mu$  and the other parameters are less stringent.

Accelerator searches are found to be complementary to direct-detection constraints. In particular, a region of the parameter space with  $m(\tilde{\chi}_1^0) \lesssim 65\text{GeV}$  and small values of the spin-independent interaction cross-section are probed by the Run-1 LHC searches. The different regions of sensitivity demonstrate clearly the importance of these complementary experimental techniques in dark matter searches.

## Acknowledgments

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d’Avenir Labex and Idex, ANR, Région Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF, Norway; Generalitat de Catalunya, Generalitat Valenciana, Spain; the Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (U.K.) and BNL (U.S.A.), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in ref. [104].

**Open Access.** This article is distributed under the terms of the Creative Commons Attribution License ([CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/)), which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

## References

- [1] Yu. A. Golfand and E.P. Likhtman, *Extension of the algebra of Poincaré group generators and violation of  $p$  invariance*, *JETP Lett.* **13** (1971) 323 [*Pisma Zh. Eksp. Teor. Fiz.* **13** (1971) 452] [[INSPIRE](#)].
- [2] D.V. Volkov and V.P. Akulov, *Is the neutrino a Goldstone particle?*, *Phys. Lett. B* **46** (1973) 109 [[INSPIRE](#)].
- [3] J. Wess and B. Zumino, *Supergauge transformations in four-dimensions*, *Nucl. Phys. B* **70** (1974) 39 [[INSPIRE](#)].
- [4] J. Wess and B. Zumino, *Supergauge invariant extension of quantum electrodynamics*, *Nucl. Phys. B* **78** (1974) 1 [[INSPIRE](#)].
- [5] S. Ferrara and B. Zumino, *Supergauge invariant Yang-Mills theories*, *Nucl. Phys. B* **79** (1974) 413 [[INSPIRE](#)].
- [6] A. Salam and J.A. Strathdee, *Supersymmetry and non-Abelian gauges*, *Phys. Lett. B* **51** (1974) 353 [[INSPIRE](#)].
- [7] S. Weinberg, *Implications of dynamical symmetry breaking*, *Phys. Rev. D* **13** (1976) 974 [[INSPIRE](#)].
- [8] E. Gildener, *Gauge symmetry hierarchies*, *Phys. Rev. D* **14** (1976) 1667 [[INSPIRE](#)].
- [9] S. Weinberg, *Implications of dynamical symmetry breaking: an addendum*, *Phys. Rev. D* **19** (1979) 1277 [[INSPIRE](#)].
- [10] L. Susskind, *Dynamics of spontaneous symmetry breaking in the Weinberg-Salam theory*, *Phys. Rev. D* **20** (1979) 2619 [[INSPIRE](#)].
- [11] H. Goldberg, *Constraint on the photino mass from cosmology*, *Phys. Rev. Lett.* **50** (1983) 1419 [*Erratum ibid.* **103** (2009) 099905] [[INSPIRE](#)].
- [12] J.R. Ellis, J.S. Hagelin, D.V. Nanopoulos, K.A. Olive and M. Srednicki, *Supersymmetric relics from the big bang*, *Nucl. Phys. B* **238** (1984) 453 [[INSPIRE](#)].
- [13] P. Fayet, *Supersymmetry and weak, electromagnetic and strong interactions*, *Phys. Lett. B* **64** (1976) 159 [[INSPIRE](#)].
- [14] P. Fayet, *Spontaneously broken supersymmetric theories of weak, electromagnetic and strong interactions*, *Phys. Lett. B* **69** (1977) 489 [[INSPIRE](#)].
- [15] A.H. Chamseddine, R.L. Arnowitt and P. Nath, *Locally supersymmetric grand unification*, *Phys. Rev. Lett.* **49** (1982) 970 [[INSPIRE](#)].
- [16] R. Barbieri, S. Ferrara and C.A. Savoy, *Gauge models with spontaneously broken local supersymmetry*, *Phys. Lett. B* **119** (1982) 343 [[INSPIRE](#)].
- [17] G.L. Kane, C.F. Kolda, L. Roszkowski and J.D. Wells, *Study of constrained minimal supersymmetry*, *Phys. Rev. D* **49** (1994) 6173 [[hep-ph/9312272](#)] [[INSPIRE](#)].
- [18] M. Dine and W. Fischler, *A phenomenological model of particle physics based on supersymmetry*, *Phys. Lett. B* **110** (1982) 227 [[INSPIRE](#)].



- [19] L. Álvarez-Gaumé, M. Claudson and M.B. Wise, *Low-energy supersymmetry*, *Nucl. Phys. B* **207** (1982) 96 [[INSPIRE](#)].
- [20] C.R. Nappi and B.A. Ovrut, *Supersymmetric extension of the  $SU(3) \times SU(2) \times U(1)$  model*, *Phys. Lett. B* **113** (1982) 175 [[INSPIRE](#)].
- [21] MSSM WORKING GROUP collaboration, A. Djouadi et al., *The minimal supersymmetric standard model: group summary report*, [hep-ph/9901246](#) [[INSPIRE](#)].
- [22] C.F. Berger, J.S. Gainer, J.L. Hewett and T.G. Rizzo, *Supersymmetry without prejudice*, *JHEP* **02** (2009) 023 [[arXiv:0812.0980](#)] [[INSPIRE](#)].
- [23] C. Strege et al., *Profile likelihood maps of a 15-dimensional MSSM*, *JHEP* **09** (2014) 081 [[arXiv:1405.0622](#)] [[INSPIRE](#)].
- [24] K.J. de Vries et al., *The pMSSM10 after LHC Run 1*, *Eur. Phys. J. C* **75** (2015) 422 [[arXiv:1504.03260](#)] [[INSPIRE](#)].
- [25] CMS collaboration, *Phenomenological MSSM interpretation of CMS searches in pp collisions at  $\sqrt{s} = 7$  and 8 TeV*, submitted to *JHEP* (2016) [[arXiv:1606.03577](#)] [[INSPIRE](#)].
- [26] ATLAS collaboration, *Summary of the ATLAS experiment's sensitivity to supersymmetry after LHC Run 1 — interpreted in the phenomenological MSSM*, *JHEP* **10** (2015) 134 [[arXiv:1508.06608](#)] [[INSPIRE](#)].
- [27] A.L. Read, *Presentation of search results: the  $CL_s$  technique*, *J. Phys. G* **28** (2002) 2693 [[INSPIRE](#)].
- [28] ATLAS collaboration, *Proposal for truth particle observable definitions in physics measurements*, [ATL-PHYS-PUB-2015-013](#), CERN, Geneva Switzerland (2015).
- [29] ATLAS collaboration, *Search for the electroweak production of supersymmetric particles in  $\sqrt{s} = 8$  TeV pp collisions with the ATLAS detector*, *Phys. Rev. D* **93** (2016) 052002 [[arXiv:1509.07152](#)] [[INSPIRE](#)].
- [30] ATLAS collaboration, *Search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum in pp collisions at  $\sqrt{s} = 8$  TeV with the ATLAS detector*, *JHEP* **05** (2014) 071 [[arXiv:1403.5294](#)] [[INSPIRE](#)].
- [31] C.G. Lester and D.J. Summers, *Measuring masses of semiinvisibly decaying particles pair produced at hadron colliders*, *Phys. Lett. B* **463** (1999) 99 [[hep-ph/9906349](#)] [[INSPIRE](#)].
- [32] A. Barr, C. Lester and P. Stephens,  *$m_{T2}$ : the truth behind the glamour*, *J. Phys. G* **29** (2003) 2343 [[hep-ph/0304226](#)] [[INSPIRE](#)].
- [33] ATLAS collaboration, *Search for the direct production of charginos, neutralinos and staus in final states with at least two hadronically decaying taus and missing transverse momentum in pp collisions at  $\sqrt{s} = 8$  TeV with the ATLAS detector*, *JHEP* **10** (2014) 096 [[arXiv:1407.0350](#)] [[INSPIRE](#)].
- [34] ATLAS collaboration, *Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in  $\sqrt{s} = 8$  TeV pp collisions with the ATLAS detector*, *JHEP* **04** (2014) 169 [[arXiv:1402.7029](#)] [[INSPIRE](#)].
- [35] ATLAS collaboration, *Search for supersymmetry in events with four or more leptons in  $\sqrt{s} = 8$  TeV pp collisions with the ATLAS detector*, *Phys. Rev. D* **90** (2014) 052001 [[arXiv:1405.5086](#)] [[INSPIRE](#)].



- [36] ATLAS collaboration, *Search for charginos nearly mass degenerate with the lightest neutralino based on a disappearing-track signature in pp collisions at  $\sqrt{s} = 8$  TeV with the ATLAS detector*, *Phys. Rev. D* **88** (2013) 112006 [[arXiv:1310.3675](#)] [[INSPIRE](#)].
- [37] ATLAS collaboration, *Search for dark matter candidates and large extra dimensions in events with a jet and missing transverse momentum with the ATLAS detector*, *JHEP* **04** (2013) 075 [[arXiv:1210.4491](#)] [[INSPIRE](#)].
- [38] F. Feroz, K. Cranmer, M. Hobson, R. Ruiz de Austri and R. Trotta, *Challenges of profile likelihood evaluation in multi-dimensional SUSY scans*, *JHEP* **06** (2011) 042 [[arXiv:1101.3296](#)] [[INSPIRE](#)].
- [39] S.S. Wilks, *The large-sample distribution of the likelihood ratio for testing composite hypotheses*, *Annals Math. Statist.* **9** (1938) 60 [[INSPIRE](#)].
- [40] F. Feroz and M.P. Hobson, *Multimodal nested sampling: an efficient and robust alternative to MCMC methods for astronomical data analysis*, *Mon. Not. Roy. Astron. Soc.* **384** (2008) 449 [[arXiv:0704.3704](#)] [[INSPIRE](#)].
- [41] F. Feroz, M.P. Hobson and M. Bridges, *MultiNest: an efficient and robust Bayesian inference tool for cosmology and particle physics*, *Mon. Not. Roy. Astron. Soc.* **398** (2009) 1601 [[arXiv:0809.3437](#)] [[INSPIRE](#)].
- [42] J. Skilling, *Nested sampling for general Bayesian computation*, *Bayesian Anal.* **1** (2006) 833.
- [43] R. Ruiz de Austri, R. Trotta and L. Roszkowski, *A Markov chain Monte Carlo analysis of the CMSSM*, *JHEP* **05** (2006) 002 [[hep-ph/0602028](#)] [[INSPIRE](#)].
- [44] R. Trotta, F. Feroz, M.P. Hobson, L. Roszkowski and R. Ruiz de Austri, *The impact of priors and observables on parameter inferences in the constrained MSSM*, *JHEP* **12** (2008) 024 [[arXiv:0809.3792](#)] [[INSPIRE](#)].
- [45] B.C. Allanach, *SOFTSUSY: a program for calculating supersymmetric spectra*, *Comput. Phys. Commun.* **143** (2002) 305 [[hep-ph/0104145](#)] [[INSPIRE](#)].
- [46] *SOFTSUSY webpage*, <http://projects.hepforge.org/softsusy/>.
- [47] G. Bélanger, F. Boudjema, A. Pukhov and A. Semenov, *MicrOMEGAs 2.0: a program to calculate the relic density of dark matter in a generic model*, *Comput. Phys. Commun.* **176** (2007) 367 [[hep-ph/0607059](#)] [[INSPIRE](#)].
- [48] *MicrOMEGAs webpage*, <http://lapth.in2p3.fr/micromegas/>.
- [49] P. Gondolo, J. Edsjo, P. Ullio, L. Bergstrom, M. Schelke and E.A. Baltz, *DarkSUSY: computing supersymmetric dark matter properties numerically*, *JCAP* **07** (2004) 008 [[astro-ph/0406204](#)] [[INSPIRE](#)].
- [50] *DarkSUSY webpage*, <http://www.darksusy.org/>.
- [51] F. Mahmoudi, *SuperIso v2.3: a program for calculating flavor physics observables in supersymmetry*, *Comput. Phys. Commun.* **180** (2009) 1579 [[arXiv:0808.3144](#)] [[INSPIRE](#)].
- [52] *SuperIso webpage*, <http://superiso.in2p3.fr/>.
- [53] G. Degrandi, P. Gambino and P. Slavich, *SusyBSG: a fortran code for  $BR[B \rightarrow X_s \gamma]$  in the MSSM with minimal flavor violation*, *Comput. Phys. Commun.* **179** (2008) 759 [[arXiv:0712.3265](#)] [[INSPIRE](#)].
- [54] *SusyBSG webpage*, <http://slavich.web.cern.ch/slavich/susybsg/>.

- [55] S. Heinemeyer, W. Hollik, A.M. Weber and G. Weiglein, *Z pole observables in the MSSM*, *JHEP* **04** (2008) 039 [[arXiv:0710.2972](#)] [[INSPIRE](#)].
- [56] ATLAS collaboration, *Measurement of the top quark mass in the  $t\bar{t} \rightarrow \text{lepton} + \text{jets}$  and  $t\bar{t} \rightarrow \text{dilepton}$  channels using  $\sqrt{s} = 7$  TeV ATLAS data*, *Eur. Phys. J. C* **75** (2015) 330 [[arXiv:1503.05427](#)] [[INSPIRE](#)].
- [57] X.L. Ren, L.S. Geng, J. Martin Camalich, J. Meng and H. Toki, *Octet baryon masses in next-to-next-to-next-to-leading order covariant baryon chiral perturbation theory*, *JHEP* **12** (2012) 073 [[arXiv:1209.3641](#)] [[INSPIRE](#)].
- [58] PARTICLE DATA GROUP collaboration, J. Beringer et al., *Review of particle physics (RPP)*, *Phys. Rev. D* **86** (2012) 010001 [[INSPIRE](#)].
- [59] P. Junnarkar and A. Walker-Loud, *Scalar strange content of the nucleon from lattice QCD*, *Phys. Rev. D* **87** (2013) 114510 [[arXiv:1301.1114](#)] [[INSPIRE](#)].
- [60] QCDSF collaboration, G.S. Bali et al., *Strangeness contribution to the proton spin from lattice QCD*, *Phys. Rev. Lett.* **108** (2012) 222001 [[arXiv:1112.3354](#)] [[INSPIRE](#)].
- [61] M. Pato, L. Baudis, G. Bertone, R. Ruiz de Austri, L.E. Strigari and R. Trotta, *Complementarity of dark matter direct detection targets*, *Phys. Rev. D* **83** (2011) 083505 [[arXiv:1012.3458](#)] [[INSPIRE](#)].
- [62] PARTICLE DATA GROUP collaboration, K.A. Olive et al., *Review of particle physics*, *Chin. Phys. C* **38** (2014) 090001 [[INSPIRE](#)].
- [63] SLD ELECTROWEAK GROUP, DELPHI, ALEPH, SLD, SLD HEAVY FLAVOUR GROUP, OPAL, LEP ELECTROWEAK WORKING GROUP and L3 collaborations, S. Schael et al., *Precision electroweak measurements on the Z resonance*, *Phys. Rept.* **427** (2006) 257 [[hep-ex/0509008](#)] [[INSPIRE](#)].
- [64] DELPHI, OPAL, LEP ELECTROWEAK, ALEPH and L3 collaborations, S. Schael et al., *Electroweak measurements in electron-positron collisions at W-boson-pair energies at LEP*, *Phys. Rept.* **532** (2013) 119 [[arXiv:1302.3415](#)] [[INSPIRE](#)].
- [65] A.G. Akeroyd and F. Mahmoudi, *Measuring  $V_{ub}$  and probing SUSY with double ratios of purely leptonic decays of B and D mesons*, *JHEP* **10** (2010) 038 [[arXiv:1007.2757](#)] [[INSPIRE](#)].
- [66] LHCb collaboration, *Measurement of the  $B_s^0 \rightarrow \mu^+ \mu^-$  branching fraction and search for  $B^0 \rightarrow \mu^+ \mu^-$  decays at the LHCb experiment*, *Phys. Rev. Lett.* **111** (2013) 101805 [[arXiv:1307.5024](#)] [[INSPIRE](#)].
- [67] PLANCK collaboration, P.A.R. Ade et al., *Planck 2013 results. XVI. Cosmological parameters*, *Astron. Astrophys.* **571** (2014) A16 [[arXiv:1303.5076](#)] [[INSPIRE](#)].
- [68] ATLAS collaboration, *Measurement of the Higgs boson mass from the  $H \rightarrow \gamma\gamma$  and  $H \rightarrow ZZ^* \rightarrow 4\ell$  channels with the ATLAS detector using  $25 \text{ fb}^{-1}$  of pp collision data*, *Phys. Rev. D* **90** (2014) 052004 [[arXiv:1406.3827](#)] [[INSPIRE](#)].
- [69] XENON100 collaboration, E. Aprile et al., *Dark matter results from 225 live days of XENON100 data*, *Phys. Rev. Lett.* **109** (2012) 181301 [[arXiv:1207.5988](#)] [[INSPIRE](#)].
- [70] XENON100 collaboration, E. Aprile et al., *Limits on spin-dependent WIMP-nucleon cross sections from 225 live days of XENON100 data*, *Phys. Rev. Lett.* **111** (2013) 021301 [[arXiv:1301.6620](#)] [[INSPIRE](#)].

- [71] LUX collaboration, D.S. Akerib et al., *First results from the LUX dark matter experiment at the Sanford Underground Research Facility*, *Phys. Rev. Lett.* **112** (2014) 091303 [[arXiv:1310.8214](#)] [[INSPIRE](#)].
- [72] CMS collaboration, *Measurement of the  $B_s^0 \rightarrow \mu^+ \mu^-$  branching fraction and search for  $B^0 \rightarrow \mu^+ \mu^-$  with the CMS experiment*, *Phys. Rev. Lett.* **111** (2013) 101804 [[arXiv:1307.5025](#)] [[INSPIRE](#)].
- [73] LHCb and CMS collaborations, *Observation of the rare  $B_s^0 \rightarrow \mu^+ \mu^-$  decay from the combined analysis of CMS and LHCb data*, *Nature* **522** (2015) 68 [[arXiv:1411.4413](#)] [[INSPIRE](#)].
- [74] G. Bertone, K. Kong, R. Ruiz de Austri and R. Trotta, *Global fits of the minimal universal extra dimensions scenario*, *Phys. Rev. D* **83** (2011) 036008 [[arXiv:1010.2023](#)] [[INSPIRE](#)].
- [75] G. Bertone, D.G. Cerdeno, M. Fornasa, R. Ruiz de Austri and R. Trotta, *Identification of dark matter particles with LHC and direct detection data*, *Phys. Rev. D* **82** (2010) 055008 [[arXiv:1005.4280](#)] [[INSPIRE](#)].
- [76] G. Bertone, D.G. Cerdeno, M. Fornasa, R. Ruiz de Austri, C. Strege and R. Trotta, *Global fits of the CMSSM including the first LHC and XENON100 data*, *JCAP* **01** (2012) 015 [[arXiv:1107.1715](#)] [[INSPIRE](#)].
- [77] C. Strege, G. Bertone, D.G. Cerdeno, M. Fornasa, R. Ruiz de Austri and R. Trotta, *Updated global fits of the CMSSM including the latest LHC SUSY and Higgs searches and XENON100 data*, *JCAP* **03** (2012) 030 [[arXiv:1112.4192](#)] [[INSPIRE](#)].
- [78] C. Savage, A. Scaffidi, M. White and A.G. Williams, *LUX likelihood and limits on spin-independent and spin-dependent WIMP couplings with LUXCalc*, *Phys. Rev. D* **92** (2015) 103519 [[arXiv:1502.02667](#)] [[INSPIRE](#)].
- [79] LUX collaboration, D.S. Akerib et al., *Improved limits on scattering of weakly interacting massive particles from reanalysis of 2013 LUX data*, *Phys. Rev. Lett.* **116** (2016) 161301 [[arXiv:1512.03506](#)] [[INSPIRE](#)].
- [80] D.S. Akerib et al., *Results from a search for dark matter in LUX with 332 live days of exposure*, [arXiv:1608.07648](#) [[INSPIRE](#)].
- [81] LUX collaboration, D.S. Akerib et al., *Results on the spin-dependent scattering of weakly interacting massive particles on nucleons from the run 3 data of the LUX experiment*, *Phys. Rev. Lett.* **116** (2016) 161302 [[arXiv:1602.03489](#)] [[INSPIRE](#)].
- [82] CMS collaboration, *Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the Standard Model predictions using proton collisions at 7 and 8 TeV*, *Eur. Phys. J. C* **75** (2015) 212 [[arXiv:1412.8662](#)] [[INSPIRE](#)].
- [83] B.C. Allanach, A. Djouadi, J.L. Kneur, W. Porod and P. Slavich, *Precise determination of the neutral Higgs boson masses in the MSSM*, *JHEP* **09** (2004) 044 [[hep-ph/0406166](#)] [[INSPIRE](#)].
- [84] ATLAS collaboration, *Constraints on new phenomena via Higgs boson couplings and invisible decays with the ATLAS detector*, *JHEP* **11** (2015) 206 [[arXiv:1509.00672](#)] [[INSPIRE](#)].
- [85] R. Ruiz de Austri, R. Trotta and L. Roszkowski, *A Markov chain Monte Carlo analysis of the CMSSM*, *JHEP* **05** (2006) 002 [[hep-ph/0602028](#)] [[INSPIRE](#)].
- [86] W. Beenakker, R. Hopker, M. Spira and P.M. Zerwas, *Squark and gluino production at hadron colliders*, *Nucl. Phys. B* **492** (1997) 51 [[hep-ph/9610490](#)] [[INSPIRE](#)].

- [87] W. Beenakker, M. Krämer, T. Plehn, M. Spira and P.M. Zerwas, *Stop production at hadron colliders*, *Nucl. Phys. B* **515** (1998) 3 [[hep-ph/9710451](#)] [[INSPIRE](#)].
- [88] W. Beenakker, M. Klasen, M. Krämer, T. Plehn, M. Spira and P.M. Zerwas, *The production of charginos/neutralinos and sleptons at hadron colliders*, *Phys. Rev. Lett.* **83** (1999) 3780 [*Erratum ibid.* **100** (2008) 029901] [[hep-ph/9906298](#)] [[INSPIRE](#)].
- [89] M. Spira, *Higgs and SUSY particle production at hadron colliders*, in *Supersymmetry and unification of fundamental interactions. Proceedings, 10<sup>th</sup> International Conference, SUSY02*, Hamburg Germany June 17–23 2002 [[hep-ph/0211145](#)] [[INSPIRE](#)].
- [90] T. Plehn, *Measuring the MSSM Lagrangean*, *Czech. J. Phys.* **55** (2005) B213 [[hep-ph/0410063](#)] [[INSPIRE](#)].
- [91] J. Alwall et al., *MadGraph/MadEvent v4: the new web generation*, *JHEP* **09** (2007) 028 [[arXiv:0706.2334](#)] [[INSPIRE](#)].
- [92] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P.M. Nadolsky and W.K. Tung, *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [[hep-ph/0201195](#)] [[INSPIRE](#)].
- [93] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [[hep-ph/0603175](#)] [[INSPIRE](#)].
- [94] ATLAS collaboration, *ATLAS tunes of PYTHIA 6 and PYTHIA 8 for MC11*, [ATL-PHYS-PUB-2011-009](#), CERN, Geneva Switzerland (2011).
- [95] S. Jadach, Z. Was, R. Decker and J.H. Kuhn, *The  $\tau$  decay library TAUOLA: version 2.4*, *Comput. Phys. Commun.* **76** (1993) 361 [[INSPIRE](#)].
- [96] P. Golonka and Z. Was, *PHOTOS Monte Carlo: a precision tool for QED corrections in Z and W decays*, *Eur. Phys. J. C* **45** (2006) 97 [[hep-ph/0506026](#)] [[INSPIRE](#)].
- [97] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250 [[INSPIRE](#)].
- [98] ATLAS collaboration, *The ATLAS simulation infrastructure*, *Eur. Phys. J. C* **70** (2010) 823 [[arXiv:1005.4568](#)] [[INSPIRE](#)].
- [99] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Gaugino production in proton-proton collisions at a center-of-mass energy of 8 TeV*, *JHEP* **10** (2012) 081 [[arXiv:1207.2159](#)] [[INSPIRE](#)].
- [100] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Precision predictions for electroweak superpartner production at hadron colliders with Resummino*, *Eur. Phys. J. C* **73** (2013) 2480 [[arXiv:1304.0790](#)] [[INSPIRE](#)].
- [101] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Revisiting slepton pair production at the Large Hadron Collider*, *JHEP* **01** (2014) 168 [[arXiv:1310.2621](#)] [[INSPIRE](#)].
- [102] M. Krämer et al., *Supersymmetry production cross sections in pp collisions at  $\sqrt{s} = 7$  TeV*, [arXiv:1206.2892](#) [[INSPIRE](#)].
- [103] M. Baak, G.J. Besjes, D. Côte, A. Koutsman, J. Lorenz and D. Short, *HistFitter software framework for statistical data analysis*, *Eur. Phys. J. C* **75** (2015) 153 [[arXiv:1410.1280](#)] [[INSPIRE](#)].
- [104] ATLAS collaboration, *ATLAS computing acknowledgements 2016–2017*, [ATL-GEN-PUB-2016-002](#), CERN, Geneva Switzerland (2016).

## The ATLAS collaboration

M. Aaboud<sup>136d</sup>, G. Aad<sup>87</sup>, B. Abbott<sup>114</sup>, J. Abdallah<sup>8</sup>, O. Abdinov<sup>12</sup>, B. Abeloos<sup>118</sup>, R. Aben<sup>108</sup>, O.S. AbouZeid<sup>138</sup>, N.L. Abraham<sup>152</sup>, H. Abramowicz<sup>156</sup>, H. Abreu<sup>155</sup>, R. Abreu<sup>117</sup>, Y. Abulaiti<sup>149a,149b</sup>, B.S. Acharya<sup>168a,168b,a</sup>, S. Adachi<sup>158</sup>, L. Adamczyk<sup>40a</sup>, D.L. Adams<sup>27</sup>, J. Adelman<sup>109</sup>, S. Adomeit<sup>101</sup>, T. Adye<sup>132</sup>, A.A. Affolder<sup>76</sup>, T. Agatonovic-Jovin<sup>14</sup>, J.A. Aguilar-Saavedra<sup>127a,127f</sup>, S.P. Ahlen<sup>24</sup>, F. Ahmadov<sup>67,b</sup>, G. Aielli<sup>134a,134b</sup>, H. Akerstedt<sup>149a,149b</sup>, T.P.A. Åkesson<sup>83</sup>, A.V. Akimov<sup>97</sup>, G.L. Alberghi<sup>22a,22b</sup>, J. Albert<sup>173</sup>, S. Albrand<sup>57</sup>, M.J. Alconada Verzini<sup>73</sup>, M. Aleksa<sup>32</sup>, I.N. Aleksandrov<sup>67</sup>, C. Alexa<sup>28b</sup>, G. Alexander<sup>156</sup>, T. Alexopoulos<sup>10</sup>, M. Alhroob<sup>114</sup>, B. Ali<sup>129</sup>, M. Aliev<sup>75a,75b</sup>, G. Alimonti<sup>93a</sup>, J. Alison<sup>33</sup>, S.P. Alkire<sup>37</sup>, B.M.M. Allbrooke<sup>152</sup>, B.W. Allen<sup>117</sup>, P.P. Allport<sup>19</sup>, A. Aloisio<sup>105a,105b</sup>, A. Alonso<sup>38</sup>, F. Alonso<sup>73</sup>, C. Alpigiani<sup>139</sup>, A.A. Alshehri<sup>55</sup>, M. Alstaty<sup>87</sup>, B. Alvarez Gonzalez<sup>32</sup>, D. Álvarez Piqueras<sup>171</sup>, M.G. Alviggi<sup>105a,105b</sup>, B.T. Amadio<sup>16</sup>, K. Amako<sup>68</sup>, Y. Amaral Coutinho<sup>26a</sup>, C. Amelung<sup>25</sup>, D. Amidei<sup>91</sup>, S.P. Amor Dos Santos<sup>127a,127c</sup>, A. Amorim<sup>127a,127b</sup>, S. Amoroso<sup>32</sup>, G. Amundsen<sup>25</sup>, C. Anastopoulos<sup>142</sup>, L.S. Ancu<sup>51</sup>, N. Andari<sup>19</sup>, T. Andeen<sup>11</sup>, C.F. Anders<sup>60b</sup>, G. Anders<sup>32</sup>, J.K. Anders<sup>76</sup>, K.J. Anderson<sup>33</sup>, A. Andreazza<sup>93a,93b</sup>, V. Andrei<sup>60a</sup>, S. Angelidakis<sup>9</sup>, I. Angelozzi<sup>108</sup>, A. Angerami<sup>37</sup>, F. Anghinolfi<sup>32</sup>, A.V. Anisenkov<sup>110,c</sup>, N. Anjos<sup>13</sup>, A. Annovi<sup>125a,125b</sup>, C. Antel<sup>60a</sup>, M. Antonelli<sup>49</sup>, A. Antonov<sup>99,\*</sup>, F. Anulli<sup>133a</sup>, M. Aoki<sup>68</sup>, L. Aperio Bella<sup>19</sup>, G. Arabidze<sup>92</sup>, Y. Arai<sup>68</sup>, J.P. Araque<sup>127a</sup>, A.T.H. Arce<sup>47</sup>, F.A. Arduh<sup>73</sup>, J-F. Arguin<sup>96</sup>, S. Argyropoulos<sup>65</sup>, M. Arik<sup>20a</sup>, A.J. Armbruster<sup>146</sup>, L.J. Armitage<sup>78</sup>, O. Arnaez<sup>32</sup>, H. Arnold<sup>50</sup>, M. Arratia<sup>30</sup>, O. Arslan<sup>23</sup>, A. Artamonov<sup>98</sup>, G. Artoni<sup>121</sup>, S. Artz<sup>85</sup>, S. Asai<sup>158</sup>, N. Asbah<sup>44</sup>, A. Ashkenazi<sup>156</sup>, B. Åsman<sup>149a,149b</sup>, L. Asquith<sup>152</sup>, K. Assamagan<sup>27</sup>, R. Astalos<sup>147a</sup>, M. Atkinson<sup>170</sup>, N.B. Atlay<sup>144</sup>, K. Augsten<sup>129</sup>, G. Avolio<sup>32</sup>, B. Axen<sup>16</sup>, M.K. Ayoub<sup>118</sup>, G. Azuelos<sup>96,d</sup>, M.A. Baak<sup>32</sup>, A.E. Baas<sup>60a</sup>, M.J. Baca<sup>19</sup>, H. Bachacou<sup>137</sup>, K. Bachas<sup>75a,75b</sup>, M. Backes<sup>121</sup>, M. Backhaus<sup>32</sup>, P. Bagiacchi<sup>133a,133b</sup>, P. Bagnaia<sup>133a,133b</sup>, Y. Bai<sup>35a</sup>, J.T. Baines<sup>132</sup>, O.K. Baker<sup>180</sup>, E.M. Baldin<sup>110,c</sup>, P. Balek<sup>176</sup>, T. Balestri<sup>151</sup>, F. Balli<sup>137</sup>, W.K. Balunas<sup>123</sup>, E. Banas<sup>41</sup>, Sw. Banerjee<sup>177,e</sup>, A.A.E. Bannoura<sup>179</sup>, L. Barak<sup>32</sup>, E.L. Barberio<sup>90</sup>, D. Barberis<sup>52a,52b</sup>, M. Barbero<sup>87</sup>, T. Barillari<sup>102</sup>, M-S Barisits<sup>32</sup>, T. Barklow<sup>146</sup>, N. Barlow<sup>30</sup>, S.L. Barnes<sup>86</sup>, B.M. Barnett<sup>132</sup>, R.M. Barnett<sup>16</sup>, Z. Barnovska-Blenessy<sup>59</sup>, A. Baroncelli<sup>135a</sup>, G. Barone<sup>25</sup>, A.J. Barr<sup>121</sup>, L. Barranco Navarro<sup>171</sup>, F. Barreiro<sup>84</sup>, J. Barreiro Guimarães da Costa<sup>35a</sup>, R. Bartoldus<sup>146</sup>, A.E. Barton<sup>74</sup>, P. Bartos<sup>147a</sup>, A. Basalae<sup>124</sup>, A. Bassalat<sup>118,f</sup>, R.L. Bates<sup>55</sup>, S.J. Batista<sup>162</sup>, J.R. Batley<sup>30</sup>, M. Battaglia<sup>138</sup>, M. Bause<sup>133a,133b</sup>, F. Bauer<sup>137</sup>, H.S. Bawa<sup>146,g</sup>, J.B. Beacham<sup>112</sup>, M.D. Beattie<sup>74</sup>, T. Beau<sup>82</sup>, P.H. Beauchemin<sup>166</sup>, P. Bechtel<sup>23</sup>, H.P. Beck<sup>18,h</sup>, K. Becker<sup>121</sup>, M. Becker<sup>85</sup>, M. Beckingham<sup>174</sup>, C. Becot<sup>111</sup>, A.J. Beddall<sup>20e</sup>, A. Beddall<sup>20b</sup>, V.A. Bednyakov<sup>67</sup>, M. Bedognetti<sup>108</sup>, C.P. Bee<sup>151</sup>, L.J. Beemster<sup>108</sup>, T.A. Beermann<sup>32</sup>, M. Begel<sup>27</sup>, J.K. Behr<sup>44</sup>, C. Belanger-Champagne<sup>89</sup>, A.S. Bell<sup>80</sup>, G. Bella<sup>156</sup>, L. Bellagamba<sup>22a</sup>, A. Bellerive<sup>31</sup>, M. Bellomo<sup>88</sup>, K. Belotskiy<sup>99</sup>, O. Beltramello<sup>32</sup>, N.L. Belyaev<sup>99</sup>, O. Benary<sup>156,\*</sup>, D. Bencheikroun<sup>136a</sup>, M. Bender<sup>101</sup>, K. Bendtz<sup>149a,149b</sup>, N. Benekos<sup>10</sup>, Y. Benhammou<sup>156</sup>, E. Benhar Nocchioli<sup>180</sup>, J. Benitez<sup>65</sup>, D.P. Benjamin<sup>47</sup>, J.R. Bensinger<sup>25</sup>, S. Bentvelsen<sup>108</sup>, L. Beresford<sup>121</sup>, M. Beretta<sup>49</sup>, D. Berge<sup>108</sup>, E. Bergeas Kuutmann<sup>169</sup>, N. Berger<sup>5</sup>, J. Beringer<sup>16</sup>, S. Berlendis<sup>57</sup>, N.R. Bernard<sup>88</sup>, C. Bernius<sup>111</sup>, F.U. Bernlochner<sup>23</sup>, T. Berry<sup>79</sup>, P. Berta<sup>130</sup>, C. Bertella<sup>85</sup>, G. Bertoli<sup>149a,149b</sup>, F. Bertolucci<sup>125a,125b</sup>, G. Bertone<sup>i</sup>, I.A. Bertram<sup>74</sup>, C. Bertsche<sup>44</sup>, D. Bertsche<sup>114</sup>, G.J. Besjes<sup>38</sup>, O. Bessidskaia Bylund<sup>149a,149b</sup>, M. Bessner<sup>44</sup>, N. Besson<sup>137</sup>, C. Betancourt<sup>50</sup>, A. Bethani<sup>57</sup>, S. Bethke<sup>102</sup>, A.J. Bevan<sup>78</sup>, R.M. Bianchi<sup>126</sup>, L. Bianchini<sup>25</sup>, M. Bianco<sup>32</sup>, O. Biebel<sup>101</sup>, D. Biedermann<sup>17</sup>, R. Bielski<sup>86</sup>, N.V. Biesuz<sup>125a,125b</sup>, M. Biglietti<sup>135a</sup>, J. Bilbao De Mendizabal<sup>51</sup>, T.R.V. Billoud<sup>96</sup>, H. Bilokon<sup>49</sup>, M. Bindi<sup>56</sup>, S. Binet<sup>118</sup>, A. Bingul<sup>20b</sup>, C. Bini<sup>133a,133b</sup>, S. Biondi<sup>22a,22b</sup>, T. Bisanz<sup>56</sup>, D.M. Bjergaard<sup>47</sup>,

C.W. Black<sup>153</sup>, J.E. Black<sup>146</sup>, K.M. Black<sup>24</sup>, D. Blackburn<sup>139</sup>, R.E. Blair<sup>6</sup>, J.-B. Blanchard<sup>137</sup>, T. Blazek<sup>147a</sup>, I. Bloch<sup>44</sup>, C. Blocker<sup>25</sup>, A. Blue<sup>55</sup>, W. Blum<sup>85,\*</sup>, U. Blumenschein<sup>56</sup>, S. Blunier<sup>34a</sup>, G.J. Bobbink<sup>108</sup>, V.S. Bobrovnikov<sup>110,c</sup>, S.S. Bocchetta<sup>83</sup>, A. Bocci<sup>47</sup>, C. Bock<sup>101</sup>, M. Boehler<sup>50</sup>, D. Boerner<sup>179</sup>, J.A. Bogaerts<sup>32</sup>, D. Bogavac<sup>14</sup>, A.G. Bogdanchikov<sup>110</sup>, C. Bohm<sup>149a</sup>, V. Boisvert<sup>79</sup>, P. Bokan<sup>14</sup>, T. Bold<sup>40a</sup>, A.S. Boldyrev<sup>168a,168c</sup>, M. Bomben<sup>82</sup>, M. Bona<sup>78</sup>, M. Boonekamp<sup>137</sup>, A. Borisov<sup>131</sup>, G. Borissov<sup>74</sup>, J. Bortfeldt<sup>32</sup>, D. Bortoletto<sup>121</sup>, V. Bortolotto<sup>62a,62b,62c</sup>, K. Bos<sup>108</sup>, D. Boscherini<sup>22a</sup>, M. Bosman<sup>13</sup>, J.D. Bossio Sola<sup>29</sup>, J. Boudreau<sup>126</sup>, J. Bouffard<sup>2</sup>, E.V. Bouhova-Thacker<sup>74</sup>, D. Boumediene<sup>36</sup>, C. Bourdarios<sup>118</sup>, S.K. Boutle<sup>55</sup>, A. Boveia<sup>32</sup>, J. Boyd<sup>32</sup>, I.R. Boyko<sup>67</sup>, J. Bracinik<sup>19</sup>, A. Brandt<sup>8</sup>, G. Brandt<sup>56</sup>, O. Brandt<sup>60a</sup>, U. Bratzler<sup>159</sup>, B. Brau<sup>88</sup>, J.E. Brau<sup>117</sup>, W.D. Breaden Madden<sup>55</sup>, K. Brendlinger<sup>123</sup>, A.J. Brennan<sup>90</sup>, L. Brenner<sup>108</sup>, R. Brenner<sup>169</sup>, S. Bressler<sup>176</sup>, T.M. Bristow<sup>48</sup>, D. Britton<sup>55</sup>, D. Britzger<sup>44</sup>, F.M. Brochu<sup>30</sup>, I. Brock<sup>23</sup>, R. Brock<sup>92</sup>, G. Brooijmans<sup>37</sup>, T. Brooks<sup>79</sup>, W.K. Brooks<sup>34b</sup>, J. Brosamer<sup>16</sup>, E. Brost<sup>109</sup>, J.H. Broughton<sup>19</sup>, P.A. Bruckman de Renstrom<sup>41</sup>, D. Bruncko<sup>147b</sup>, R. Bruneliere<sup>50</sup>, A. Bruni<sup>22a</sup>, G. Bruni<sup>22a</sup>, L.S. Bruni<sup>108</sup>, B.H. Brunt<sup>30</sup>, M. Bruschi<sup>22a</sup>, N. Bruscino<sup>23</sup>, P. Bryant<sup>33</sup>, L. Bryngemark<sup>83</sup>, T. Buanes<sup>15</sup>, Q. Buat<sup>145</sup>, P. Buchholz<sup>144</sup>, A.G. Buckley<sup>55</sup>, I.A. Budagov<sup>67</sup>, F. Buehrer<sup>50</sup>, M.K. Bugge<sup>120</sup>, O. Bulekov<sup>99</sup>, D. Bullock<sup>8</sup>, H. Burckhart<sup>32</sup>, S. Burdin<sup>76</sup>, C.D. Burgard<sup>50</sup>, B. Burghgrave<sup>109</sup>, K. Burka<sup>41</sup>, S. Burke<sup>132</sup>, I. Burmeister<sup>45</sup>, J.T.P. Burr<sup>121</sup>, E. Busato<sup>36</sup>, D. B scher<sup>50</sup>, V. B scher<sup>85</sup>, P. Bussey<sup>55</sup>, J.M. Butler<sup>24</sup>, C.M. Buttar<sup>55</sup>, J.M. Butterworth<sup>80</sup>, P. Butti<sup>108</sup>, W. Buttinger<sup>27</sup>, A. Buzatu<sup>55</sup>, A.R. Buzykaev<sup>110,c</sup>, S. Cabrera Urb n<sup>171</sup>, D. Caforio<sup>129</sup>, V.M. Cairo<sup>39a,39b</sup>, O. Cakir<sup>4a</sup>, N. Calace<sup>51</sup>, P. Calafiura<sup>16</sup>, A. Calandri<sup>87</sup>, G. Calderini<sup>82</sup>, P. Calfayan<sup>63</sup>, G. Callea<sup>39a,39b</sup>, L.P. Caloba<sup>26a</sup>, S. Calvente Lopez<sup>84</sup>, D. Calvet<sup>36</sup>, S. Calvet<sup>36</sup>, T.P. Calvet<sup>87</sup>, R. Camacho Toro<sup>33</sup>, S. Camarda<sup>32</sup>, P. Camarri<sup>134a,134b</sup>, D. Cameron<sup>120</sup>, R. Caminal Armadans<sup>170</sup>, C. Camincher<sup>57</sup>, S. Campana<sup>32</sup>, M. Campanelli<sup>80</sup>, A. Camplani<sup>93a,93b</sup>, A. Campoverde<sup>144</sup>, V. Canale<sup>105a,105b</sup>, A. Canepa<sup>164a</sup>, M. Cano Bret<sup>141</sup>, J. Cantero<sup>115</sup>, T. Cao<sup>42</sup>, M.D.M. Capeans Garrido<sup>32</sup>, I. Caprini<sup>28b</sup>, M. Caprini<sup>28b</sup>, M. Capua<sup>39a,39b</sup>, R.M. Carbone<sup>37</sup>, R. Cardarelli<sup>134a</sup>, F. Cardillo<sup>50</sup>, I. Carli<sup>130</sup>, T. Carli<sup>32</sup>, G. Carlino<sup>105a</sup>, L. Carminati<sup>93a,93b</sup>, S. Caron<sup>107</sup>, E. Carquin<sup>34b</sup>, G.D. Carrillo-Montoya<sup>32</sup>, J.R. Carter<sup>30</sup>, J. Carvalho<sup>127a,127c</sup>, D. Casadei<sup>19</sup>, M.P. Casado<sup>13,j</sup>, M. Casolino<sup>13</sup>, D.W. Casper<sup>167</sup>, E. Castaneda-Miranda<sup>148a</sup>, R. Castelijns<sup>108</sup>, A. Castelli<sup>108</sup>, V. Castillo Gimenez<sup>171</sup>, N.F. Castro<sup>127a,k</sup>, A. Catinaccio<sup>32</sup>, J.R. Catmore<sup>120</sup>, A. Cattai<sup>32</sup>, J. Caudron<sup>23</sup>, V. Cavaliere<sup>170</sup>, E. Cavallaro<sup>13</sup>, D. Cavalli<sup>93a</sup>, M. Cavalli-Sforza<sup>13</sup>, V. Cavasinni<sup>125a,125b</sup>, F. Ceradini<sup>135a,135b</sup>, L. Cerda Alberich<sup>171</sup>, A.S. Cerqueira<sup>26b</sup>, A. Cerri<sup>152</sup>, L. Cerrito<sup>134a,134b</sup>, F. Cerutti<sup>16</sup>, M. Cerv<sup>32</sup>, A. Cervelli<sup>18</sup>, S.A. Cetin<sup>20d</sup>, A. Chafaq<sup>136a</sup>, D. Chakraborty<sup>109</sup>, S.K. Chan<sup>58</sup>, Y.L. Chan<sup>62a</sup>, P. Chang<sup>170</sup>, J.D. Chapman<sup>30</sup>, D.G. Charlton<sup>19</sup>, A. Chatterjee<sup>51</sup>, C.C. Chau<sup>162</sup>, C.A. Chavez Barajas<sup>152</sup>, S. Che<sup>112</sup>, S. Cheatham<sup>168a,168c</sup>, A. Chegwidden<sup>92</sup>, S. Chekanov<sup>6</sup>, S.V. Chekulaev<sup>164a</sup>, G.A. Chelkov<sup>67,l</sup>, M.A. Chelstowska<sup>91</sup>, C. Chen<sup>66</sup>, H. Chen<sup>27</sup>, K. Chen<sup>151</sup>, S. Chen<sup>35b</sup>, S. Chen<sup>158</sup>, X. Chen<sup>35c</sup>, Y. Chen<sup>69</sup>, H.C. Cheng<sup>91</sup>, H.J. Cheng<sup>35a</sup>, Y. Cheng<sup>33</sup>, A. Cheplakov<sup>67</sup>, E. Cheremushkina<sup>131</sup>, R. Cherkaoui El Moursli<sup>136e</sup>, V. Chernyatin<sup>27,\*</sup>, E. Cheu<sup>7</sup>, L. Chevalier<sup>137</sup>, V. Chiarella<sup>49</sup>, G. Chiarelli<sup>125a,125b</sup>, G. Chiodini<sup>75a</sup>, A.S. Chisholm<sup>32</sup>, A. Chitan<sup>28b</sup>, M.V. Chizhov<sup>67</sup>, K. Choi<sup>63</sup>, A.R. Chomont<sup>36</sup>, S. Chouridou<sup>9</sup>, B.K.B. Chow<sup>101</sup>, V. Christodoulou<sup>80</sup>, D. Chromek-Burckhart<sup>32</sup>, J. Chudoba<sup>128</sup>, A.J. Chuinard<sup>89</sup>, J.J. Chwastowski<sup>41</sup>, L. Chytka<sup>116</sup>, G. Ciapetti<sup>133a,133b</sup>, A.K. Ciftci<sup>4a</sup>, D. Cinca<sup>45</sup>, V. Cindro<sup>77</sup>, I.A. Cioara<sup>23</sup>, C. Ciocca<sup>22a,22b</sup>, A. Ciocio<sup>16</sup>, F. Ciotto<sup>105a,105b</sup>, Z.H. Citron<sup>176</sup>, M. Citterio<sup>93a</sup>, M. Ciubancan<sup>28b</sup>, A. Clark<sup>51</sup>, B.L. Clark<sup>58</sup>, M.R. Clark<sup>37</sup>, P.J. Clark<sup>48</sup>, R.N. Clarke<sup>16</sup>, C. Clement<sup>149a,149b</sup>, Y. Coadou<sup>87</sup>, M. Cobal<sup>168a,168c</sup>, A. Coccaro<sup>51</sup>, J. Cochran<sup>66</sup>, L. Colasurdo<sup>107</sup>, B. Cole<sup>37</sup>, A.P. Colijn<sup>108</sup>, J. Collot<sup>57</sup>, T. Colombo<sup>167</sup>, G. Compostella<sup>102</sup>, P. Conde Mui o<sup>127a,127b</sup>, E. Coniavitis<sup>50</sup>, S.H. Connell<sup>148b</sup>, I.A. Connelly<sup>79</sup>, V. Consorti<sup>50</sup>, S. Constantinescu<sup>28b</sup>, G. Conti<sup>32</sup>, F. Conventi<sup>105a,m</sup>, M. Cooke<sup>16</sup>, B.D. Cooper<sup>80</sup>,

A.M. Cooper-Sarkar<sup>121</sup>, K.J.R. Cormier<sup>162</sup>, T. Cornelissen<sup>179</sup>, M. Corradi<sup>133a,133b</sup>,  
F. Corriveau<sup>89,n</sup>, A. Cortes-Gonzalez<sup>32</sup>, G. Cortiana<sup>102</sup>, G. Costa<sup>93a</sup>, M.J. Costa<sup>171</sup>,  
D. Costanzo<sup>142</sup>, G. Cottin<sup>30</sup>, G. Cowan<sup>79</sup>, B.E. Cox<sup>86</sup>, K. Cranmer<sup>111</sup>, S.J. Crawley<sup>55</sup>, G. Cree<sup>31</sup>,  
S. Crépé-Renaudin<sup>57</sup>, F. Crescioli<sup>82</sup>, W.A. Cribbs<sup>149a,149b</sup>, M. Crispin Ortuzar<sup>121</sup>,  
M. Cristinziani<sup>23</sup>, V. Croft<sup>107</sup>, G. Crosetti<sup>39a,39b</sup>, A. Cueto<sup>84</sup>, T. Cuhadar Donszelmann<sup>142</sup>,  
J. Cummings<sup>180</sup>, M. Curatolo<sup>49</sup>, J. Cúth<sup>85</sup>, H. Czirr<sup>144</sup>, P. Czodrowski<sup>3</sup>, G. D'amen<sup>22a,22b</sup>,  
S. D'Auria<sup>55</sup>, M. D'Onofrio<sup>76</sup>, M.J. Da Cunha Sargedas De Sousa<sup>127a,127b</sup>, C. Da Via<sup>86</sup>,  
W. Dabrowski<sup>40a</sup>, T. Dado<sup>147a</sup>, T. Dai<sup>91</sup>, O. Dale<sup>15</sup>, F. Dallaire<sup>96</sup>, C. Dallapiccola<sup>88</sup>, M. Dam<sup>38</sup>,  
J.R. Dandoy<sup>33</sup>, N.P. Dang<sup>50</sup>, A.C. Daniells<sup>19</sup>, N.S. Dann<sup>86</sup>, M. Danninger<sup>172</sup>,  
M. Dano Hoffmann<sup>137</sup>, V. Dao<sup>50</sup>, G. Darbo<sup>52a</sup>, S. Darmora<sup>8</sup>, J. Dassoulas<sup>3</sup>, A. Dattagupta<sup>117</sup>,  
W. Davey<sup>23</sup>, C. David<sup>173</sup>, T. Davidek<sup>130</sup>, M. Davies<sup>156</sup>, P. Davison<sup>80</sup>, E. Dawe<sup>90</sup>, I. Dawson<sup>142</sup>,  
K. De<sup>8</sup>, R. de Asmundis<sup>105a</sup>, A. De Benedetti<sup>114</sup>, S. De Castro<sup>22a,22b</sup>, S. De Cecco<sup>82</sup>,  
N. De Groot<sup>107</sup>, P. de Jong<sup>108</sup>, H. De la Torre<sup>92</sup>, F. De Lorenzi<sup>66</sup>, A. De Maria<sup>56</sup>, D. De Pedis<sup>133a</sup>,  
A. De Salvo<sup>133a</sup>, U. De Sanctis<sup>152</sup>, A. De Santo<sup>152</sup>, J.B. De Vivie De Regie<sup>118</sup>, W.J. Dearnaley<sup>74</sup>,  
R. Debbé<sup>27</sup>, C. Debenedetti<sup>138</sup>, D.V. Dedovich<sup>67</sup>, N. Dehghanian<sup>3</sup>, I. Deigaard<sup>108</sup>,  
M. Del Gaudio<sup>39a,39b</sup>, J. Del Peso<sup>84</sup>, T. Del Prete<sup>125a,125b</sup>, D. Delgove<sup>118</sup>, F. Deliot<sup>137</sup>,  
C.M. Delitzsch<sup>51</sup>, A. Dell'Acqua<sup>32</sup>, L. Dell'Asta<sup>24</sup>, M. Dell'Orso<sup>125a,125b</sup>, M. Della Pietra<sup>105a,m</sup>,  
D. della Volpe<sup>51</sup>, M. Delmastro<sup>5</sup>, P.A. Delsart<sup>57</sup>, D.A. DeMarco<sup>162</sup>, S. Demers<sup>180</sup>, M. Demichev<sup>67</sup>,  
A. Demilly<sup>82</sup>, S.P. Denisov<sup>131</sup>, D. Denysiuk<sup>137</sup>, D. Derendarz<sup>41</sup>, J.E. Derkaoui<sup>136d</sup>, F. Derue<sup>82</sup>,  
P. Dervan<sup>76</sup>, K. Desch<sup>23</sup>, C. Deterre<sup>44</sup>, K. Dette<sup>45</sup>, P.O. Deviveiros<sup>32</sup>, A. Dewhurst<sup>132</sup>,  
S. Dhaliwal<sup>25</sup>, A. Di Ciaccio<sup>134a,134b</sup>, L. Di Ciaccio<sup>5</sup>, W.K. Di Clemente<sup>123</sup>, C. Di Donato<sup>133a,133b</sup>,  
A. Di Girolamo<sup>32</sup>, B. Di Girolamo<sup>32</sup>, B. Di Micco<sup>135a,135b</sup>, R. Di Nardo<sup>32</sup>, A. Di Simone<sup>50</sup>,  
R. Di Sipio<sup>162</sup>, D. Di Valentino<sup>31</sup>, C. Diaconu<sup>87</sup>, M. Diamond<sup>162</sup>, F.A. Dias<sup>48</sup>, M.A. Diaz<sup>34a</sup>,  
E.B. Diehl<sup>91</sup>, J. Dietrich<sup>17</sup>, S. Díez Cornell<sup>44</sup>, A. Dimitrievska<sup>14</sup>, J. Dingfelder<sup>23</sup>, P. Dita<sup>28b</sup>,  
S. Dita<sup>28b</sup>, F. Dittus<sup>32</sup>, F. Djama<sup>87</sup>, T. Djobava<sup>53b</sup>, J.I. Djuvsland<sup>60a</sup>, M.A.B. do Vale<sup>26c</sup>,  
D. Dobos<sup>32</sup>, M. Dobre<sup>28b</sup>, C. Doglioni<sup>83</sup>, J. Dolejsi<sup>130</sup>, Z. Dolezal<sup>130</sup>, M. Donadelli<sup>26d</sup>,  
S. Donati<sup>125a,125b</sup>, P. Dondero<sup>122a,122b</sup>, J. Donini<sup>36</sup>, J. Dopke<sup>132</sup>, A. Doria<sup>105a</sup>, M.T. Dova<sup>73</sup>,  
A.T. Doyle<sup>55</sup>, E. Drechsler<sup>56</sup>, M. Dris<sup>10</sup>, Y. Du<sup>140</sup>, J. Duarte-Campderros<sup>156</sup>, E. Duchovni<sup>176</sup>,  
G. Duckeck<sup>101</sup>, O.A. Ducu<sup>96,o</sup>, D. Duda<sup>108</sup>, A. Dudarev<sup>32</sup>, A.Chr. Dudder<sup>85</sup>, E.M. Duffield<sup>16</sup>,  
L. Dufflot<sup>118</sup>, M. Dührssen<sup>32</sup>, M. Dumancic<sup>176</sup>, M. Dunford<sup>60a</sup>, H. Duran Yildiz<sup>4a</sup>, M. Düren<sup>54</sup>,  
A. Durglishvili<sup>53b</sup>, D. Duschinger<sup>46</sup>, B. Dutta<sup>44</sup>, M. Dyndal<sup>44</sup>, C. Eckardt<sup>44</sup>, K.M. Ecker<sup>102</sup>,  
R.C. Edgar<sup>91</sup>, N.C. Edwards<sup>48</sup>, T. Eifert<sup>32</sup>, G. Eigen<sup>15</sup>, K. Einsweiler<sup>16</sup>, T. Ekelof<sup>169</sup>,  
M. El Kacimi<sup>136c</sup>, V. Ellajosyula<sup>87</sup>, M. Ellert<sup>169</sup>, S. Elles<sup>5</sup>, F. Ellinghaus<sup>179</sup>, A.A. Elliot<sup>173</sup>,  
N. Ellis<sup>32</sup>, J. Elmsheuser<sup>27</sup>, M. Elsing<sup>32</sup>, D. Emeliyanov<sup>132</sup>, Y. Enari<sup>158</sup>, O.C. Endner<sup>85</sup>,  
J.S. Ennis<sup>174</sup>, J. Erdmann<sup>45</sup>, A. Ereditato<sup>18</sup>, G. Ernis<sup>179</sup>, J. Ernst<sup>2</sup>, M. Ernst<sup>27</sup>, S. Errede<sup>170</sup>,  
E. Ertel<sup>85</sup>, M. Escalier<sup>118</sup>, H. Esch<sup>45</sup>, C. Escobar<sup>126</sup>, B. Esposito<sup>49</sup>, A.I. Etienne<sup>137</sup>, E. Etzion<sup>156</sup>,  
H. Evans<sup>63</sup>, A. Ezhilov<sup>124</sup>, M. Ezzi<sup>136e</sup>, F. Fabbri<sup>22a,22b</sup>, L. Fabbri<sup>22a,22b</sup>, G. Facini<sup>33</sup>,  
R.M. Fakhruddinov<sup>131</sup>, S. Falciano<sup>133a</sup>, R.J. Falla<sup>80</sup>, J. Faltova<sup>32</sup>, Y. Fang<sup>35a</sup>, M. Fanti<sup>93a,93b</sup>,  
A. Farbin<sup>8</sup>, A. Farilla<sup>135a</sup>, C. Farina<sup>126</sup>, E.M. Farina<sup>122a,122b</sup>, T. Farooque<sup>13</sup>, S. Farrell<sup>16</sup>,  
S.M. Farrington<sup>174</sup>, P. Farthouat<sup>32</sup>, F. Fassi<sup>136e</sup>, P. Fassnacht<sup>32</sup>, D. Fassouliotis<sup>9</sup>,  
M. Fauci Giannelli<sup>79</sup>, A. Favareto<sup>52a,52b</sup>, W.J. Fawcett<sup>121</sup>, L. Fayard<sup>118</sup>, O.L. Fedin<sup>124,p</sup>,  
W. Fedorko<sup>172</sup>, S. Feigl<sup>120</sup>, L. Feligioni<sup>87</sup>, C. Feng<sup>140</sup>, E.J. Feng<sup>32</sup>, H. Feng<sup>91</sup>, A.B. Fenyuk<sup>131</sup>,  
L. Feremenga<sup>8</sup>, P. Fernandez Martinez<sup>171</sup>, S. Fernandez Perez<sup>13</sup>, J. Ferrando<sup>44</sup>, A. Ferrari<sup>169</sup>,  
P. Ferrari<sup>108</sup>, R. Ferrari<sup>122a</sup>, D.E. Ferreira de Lima<sup>60b</sup>, A. Ferrer<sup>171</sup>, D. Ferrere<sup>51</sup>, C. Ferretti<sup>91</sup>,  
A. Ferretto Parodi<sup>52a,52b</sup>, F. Fiedler<sup>85</sup>, A. Filipčič<sup>77</sup>, M. Filipuzzi<sup>44</sup>, F. Filthaut<sup>107</sup>,  
M. Fincke-Keeler<sup>173</sup>, K.D. Finelli<sup>153</sup>, M.C.N. Fiolhais<sup>127a,127c</sup>, L. Fiorini<sup>171</sup>, A. Firani<sup>42</sup>,  
A. Fischer<sup>2</sup>, C. Fischer<sup>13</sup>, J. Fischer<sup>179</sup>, W.C. Fisher<sup>92</sup>, N. Flaschel<sup>44</sup>, I. Fleck<sup>144</sup>,  
P. Fleischmann<sup>91</sup>, G.T. Fletcher<sup>142</sup>, R.R.M. Fletcher<sup>123</sup>, T. Flick<sup>179</sup>, L.R. Flores Castillo<sup>62a</sup>,



M.J. Flowerdew<sup>102</sup>, G.T. Forcolin<sup>86</sup>, A. Formica<sup>137</sup>, A. Forti<sup>86</sup>, A.G. Foster<sup>19</sup>, D. Fournier<sup>118</sup>, H. Fox<sup>74</sup>, S. Fracchia<sup>13</sup>, P. Francavilla<sup>82</sup>, M. Franchini<sup>22a,22b</sup>, D. Francis<sup>32</sup>, L. Franconi<sup>120</sup>, M. Franklin<sup>58</sup>, M. Frate<sup>167</sup>, M. Fraternali<sup>122a,122b</sup>, D. Freeborn<sup>80</sup>, S.M. Fressard-Batraneanu<sup>32</sup>, F. Friedrich<sup>46</sup>, D. Froidevaux<sup>32</sup>, J.A. Frost<sup>121</sup>, C. Fukunaga<sup>159</sup>, E. Fullana Torregrosa<sup>85</sup>, T. Fusayasu<sup>103</sup>, J. Fuster<sup>171</sup>, C. Gabaldon<sup>57</sup>, O. Gabizon<sup>155</sup>, A. Gabrielli<sup>22a,22b</sup>, A. Gabrielli<sup>16</sup>, G.P. Gach<sup>40a</sup>, S. Gadatsch<sup>32</sup>, S. Gadomski<sup>79</sup>, G. Gagliardi<sup>52a,52b</sup>, L.G. Gagnon<sup>96</sup>, P. Gagnon<sup>63</sup>, C. Galea<sup>107</sup>, B. Galhardo<sup>127a,127c</sup>, E.J. Gallas<sup>121</sup>, B.J. Gallop<sup>132</sup>, P. Gallus<sup>129</sup>, G. Galster<sup>38</sup>, K.K. Gan<sup>112</sup>, J. Gao<sup>59</sup>, Y. Gao<sup>48</sup>, Y.S. Gao<sup>146,g</sup>, F.M. Garay Walls<sup>48</sup>, C. García<sup>171</sup>, J.E. García Navarro<sup>171</sup>, M. Garcia-Sciveres<sup>16</sup>, R.W. Gardner<sup>33</sup>, N. Garelli<sup>146</sup>, V. Garonne<sup>120</sup>, A. Gascon Bravo<sup>44</sup>, K. Gasnikova<sup>44</sup>, C. Gatti<sup>49</sup>, A. Gaudiello<sup>52a,52b</sup>, G. Gaudio<sup>122a</sup>, L. Gauthier<sup>96</sup>, I.L. Gavrilenko<sup>97</sup>, C. Gay<sup>172</sup>, G. Gaycken<sup>23</sup>, E.N. Gazis<sup>10</sup>, Z. Gecse<sup>172</sup>, C.N.P. Gee<sup>132</sup>, Ch. Geich-Gimbel<sup>23</sup>, M. Geisen<sup>85</sup>, M.P. Geisler<sup>60a</sup>, K. Gellerstedt<sup>149a,149b</sup>, C. Gemme<sup>52a</sup>, M.H. Genest<sup>57</sup>, C. Geng<sup>59,q</sup>, S. Gentile<sup>133a,133b</sup>, C. Gentsos<sup>157</sup>, S. George<sup>79</sup>, D. Gerbaudo<sup>13</sup>, A. Gershon<sup>156</sup>, S. Ghasemi<sup>144</sup>, M. Ghneimat<sup>23</sup>, B. Giacobbe<sup>22a</sup>, S. Giagu<sup>133a,133b</sup>, P. Giannetti<sup>125a,125b</sup>, B. Gibbard<sup>27</sup>, S.M. Gibson<sup>79</sup>, M. Gignac<sup>172</sup>, M. Gilchriese<sup>16</sup>, T.P.S. Gillam<sup>30</sup>, D. Gillberg<sup>31</sup>, G. Gilles<sup>179</sup>, D.M. Gingrich<sup>3,d</sup>, N. Giokaris<sup>9</sup>, M.P. Giordani<sup>168a,168c</sup>, F.M. Giorgi<sup>22a</sup>, F.M. Giorgi<sup>17</sup>, P.F. Giraud<sup>137</sup>, P. Giromini<sup>58</sup>, D. Giugni<sup>93a</sup>, F. Giuli<sup>121</sup>, C. Giuliani<sup>102</sup>, M. Giulini<sup>60b</sup>, B.K. Gjølsten<sup>120</sup>, S. Gkaitatzis<sup>157</sup>, I. Gkialas<sup>157</sup>, E.L. Gkougkousis<sup>118</sup>, L.K. Gladilin<sup>100</sup>, C. Glasman<sup>84</sup>, J. Glatzer<sup>50</sup>, P.C.F. Glazys<sup>48</sup>, A. Glazov<sup>44</sup>, M. Goblirsch-Kolb<sup>25</sup>, J. Godlewski<sup>41</sup>, S. Goldfarb<sup>90</sup>, T. Golling<sup>51</sup>, D. Golubkov<sup>131</sup>, A. Gomes<sup>127a,127b,127d</sup>, R. Gonçalves<sup>127a</sup>, J. Goncalves Pinto Firmino Da Costa<sup>137</sup>, G. Gonella<sup>50</sup>, L. Gonella<sup>19</sup>, A. Gongadze<sup>67</sup>, S. González de la Hoz<sup>171</sup>, S. Gonzalez-Sevilla<sup>51</sup>, L. Goossens<sup>32</sup>, P.A. Gorbounov<sup>98</sup>, H.A. Gordon<sup>27</sup>, I. Gorelov<sup>106</sup>, B. Gorini<sup>32</sup>, E. Gorini<sup>75a,75b</sup>, A. Gorišek<sup>77</sup>, E. Gornicki<sup>41</sup>, A.T. Goshaw<sup>47</sup>, C. Gössling<sup>45</sup>, M.I. Gostkin<sup>67</sup>, C.R. Goudet<sup>118</sup>, D. Goujdami<sup>136c</sup>, A.G. Goussiou<sup>139</sup>, N. Govender<sup>148b,r</sup>, E. Gozani<sup>155</sup>, L. Graber<sup>56</sup>, I. Grabowska-Bold<sup>40a</sup>, P.O.J. Gradin<sup>57</sup>, P. Grafström<sup>22a,22b</sup>, J. Gramling<sup>51</sup>, E. Gramstad<sup>120</sup>, S. Grancagnolo<sup>17</sup>, V. Gratchev<sup>124</sup>, P.M. Gravila<sup>28e</sup>, H.M. Gray<sup>32</sup>, E. Graziani<sup>135a</sup>, Z.D. Greenwood<sup>81,s</sup>, C. Greife<sup>23</sup>, K. Gregersen<sup>80</sup>, I.M. Gregor<sup>44</sup>, P. Grenier<sup>146</sup>, K. Grevtsov<sup>5</sup>, J. Griffiths<sup>8</sup>, A.A. Grillo<sup>138</sup>, K. Grimm<sup>74</sup>, S. Grinstein<sup>13,t</sup>, Ph. Gris<sup>36</sup>, J.-F. Grivaz<sup>118</sup>, S. Groh<sup>85</sup>, E. Gross<sup>176</sup>, J. Grosse-Knetter<sup>56</sup>, G.C. Grossi<sup>81</sup>, Z.J. Grout<sup>80</sup>, L. Guan<sup>91</sup>, W. Guan<sup>177</sup>, J. Guenther<sup>64</sup>, F. Guescini<sup>51</sup>, D. Guest<sup>167</sup>, O. Gueta<sup>156</sup>, B. Gui<sup>112</sup>, E. Guido<sup>52a,52b</sup>, T. Guillemin<sup>5</sup>, S. Guindon<sup>2</sup>, U. Gul<sup>55</sup>, C. Gumpert<sup>32</sup>, J. Guo<sup>141</sup>, Y. Guo<sup>59,q</sup>, R. Gupta<sup>42</sup>, S. Gupta<sup>121</sup>, G. Gustavino<sup>133a,133b</sup>, P. Gutierrez<sup>114</sup>, N.G. Gutierrez Ortiz<sup>80</sup>, C. Gutschow<sup>46</sup>, C. Guyot<sup>137</sup>, C. Gwenlan<sup>121</sup>, C.B. Gwilliam<sup>76</sup>, A. Haas<sup>111</sup>, C. Haber<sup>16</sup>, H.K. Hadavand<sup>8</sup>, N. Haddad<sup>136e</sup>, A. Hadei<sup>87</sup>, S. Hageböck<sup>23</sup>, M. Hagihara<sup>165</sup>, Z. Hajduk<sup>41</sup>, H. Hakobyan<sup>181,\*</sup>, M. Haleem<sup>44</sup>, J. Haley<sup>115</sup>, G. Halladjian<sup>92</sup>, G.D. Hallewell<sup>87</sup>, K. Hamacher<sup>179</sup>, P. Hamal<sup>116</sup>, K. Hamano<sup>173</sup>, A. Hamilton<sup>148a</sup>, G.N. Hamity<sup>142</sup>, P.G. Hamnett<sup>44</sup>, L. Han<sup>59</sup>, K. Hanagaki<sup>68,u</sup>, K. Hanawa<sup>158</sup>, M. Hance<sup>138</sup>, B. Haney<sup>123</sup>, P. Hanke<sup>60a</sup>, R. Hanna<sup>137</sup>, J.B. Hansen<sup>38</sup>, J.D. Hansen<sup>38</sup>, M.C. Hansen<sup>23</sup>, P.H. Hansen<sup>38</sup>, K. Hara<sup>165</sup>, A.S. Hard<sup>177</sup>, T. Harenberg<sup>179</sup>, F. Hariri<sup>118</sup>, S. Harkusha<sup>94</sup>, R.D. Harrington<sup>48</sup>, P.F. Harrison<sup>174</sup>, F. Hartjes<sup>108</sup>, N.M. Hartmann<sup>101</sup>, M. Hasegawa<sup>69</sup>, Y. Hasegawa<sup>143</sup>, A. Hasib<sup>114</sup>, S. Hassani<sup>137</sup>, S. Haug<sup>18</sup>, R. Hauser<sup>92</sup>, L. Hauswald<sup>46</sup>, M. Havranek<sup>128</sup>, C.M. Hawkes<sup>19</sup>, R.J. Hawkins<sup>32</sup>, D. Hayakawa<sup>160</sup>, D. Hayden<sup>92</sup>, C.P. Hays<sup>121</sup>, J.M. Hays<sup>78</sup>, H.S. Hayward<sup>76</sup>, S.J. Haywood<sup>132</sup>, S.J. Head<sup>19</sup>, T. Heck<sup>85</sup>, V. Hedberg<sup>83</sup>, L. Heelan<sup>8</sup>, S. Heim<sup>123</sup>, T. Heim<sup>16</sup>, B. Heinemann<sup>16</sup>, J.J. Heinrich<sup>101</sup>, L. Heinrich<sup>111</sup>, C. Heinz<sup>54</sup>, J. Hejbal<sup>128</sup>, L. Helary<sup>32</sup>, S. Hellman<sup>149a,149b</sup>, C. Helsens<sup>32</sup>, J. Henderson<sup>121</sup>, R.C.W. Henderson<sup>74</sup>, Y. Heng<sup>177</sup>, S. Henkelmann<sup>172</sup>, A.M. Henriques Correia<sup>32</sup>, S. Henrot-Versille<sup>118</sup>, G.H. Herbert<sup>17</sup>, H. Herde<sup>25</sup>, V. Herget<sup>178</sup>, Y. Hernández Jiménez<sup>171</sup>, G. Herten<sup>50</sup>, R. Hertenberger<sup>101</sup>, L. Hervas<sup>32</sup>, G.G. Hesketh<sup>80</sup>, N.P. Hessey<sup>108</sup>, J.W. Hetherly<sup>42</sup>,



R. Hickling<sup>78</sup>, E. Higón-Rodríguez<sup>171</sup>, E. Hill<sup>173</sup>, J.C. Hill<sup>30</sup>, K.H. Hiller<sup>44</sup>, S.J. Hillier<sup>19</sup>, I. Hinchliffe<sup>16</sup>, E. Hines<sup>123</sup>, R.R. Hinman<sup>16</sup>, M. Hirose<sup>50</sup>, D. Hirschbuehl<sup>179</sup>, J. Hobbs<sup>151</sup>, N. Hod<sup>164a</sup>, M.C. Hodgkinson<sup>142</sup>, P. Hodgson<sup>142</sup>, A. Hoecker<sup>32</sup>, M.R. Hoefkamp<sup>106</sup>, F. Hoenig<sup>101</sup>, D. Hohn<sup>23</sup>, T.R. Holmes<sup>16</sup>, M. Homann<sup>45</sup>, T. Honda<sup>68</sup>, T.M. Hong<sup>126</sup>, B.H. Hooberman<sup>170</sup>, W.H. Hopkins<sup>117</sup>, Y. Horii<sup>104</sup>, A.J. Horton<sup>145</sup>, J.-Y. Hostachy<sup>57</sup>, S. Hou<sup>154</sup>, A. Hoummada<sup>136a</sup>, J. Howarth<sup>44</sup>, J. Hoya<sup>73</sup>, M. Hrabovsky<sup>116</sup>, I. Hristova<sup>17</sup>, J. Hrivnac<sup>118</sup>, T. Hryn'ova<sup>5</sup>, A. Hrynevich<sup>95</sup>, C. Hsu<sup>148c</sup>, P.J. Hsu<sup>154,v</sup>, S.-C. Hsu<sup>139</sup>, Q. Hu<sup>59</sup>, S. Hu<sup>141</sup>, Y. Huang<sup>44</sup>, Z. Hubacek<sup>129</sup>, F. Hubaut<sup>87</sup>, F. Huegging<sup>23</sup>, T.B. Huffman<sup>121</sup>, E.W. Hughes<sup>37</sup>, G. Hughes<sup>74</sup>, M. Huhtinen<sup>32</sup>, P. Huo<sup>151</sup>, N. Huseynov<sup>67,b</sup>, J. Huston<sup>92</sup>, J. Huth<sup>58</sup>, G. Iacobucci<sup>51</sup>, G. Iakovidis<sup>27</sup>, I. Ibragimov<sup>144</sup>, L. Iconomidou-Fayard<sup>118</sup>, E. Ideal<sup>180</sup>, Z. Idrissi<sup>136e</sup>, P. Iengo<sup>32</sup>, O. Igonkina<sup>108,w</sup>, T. Iizawa<sup>175</sup>, Y. Ikegami<sup>68</sup>, M. Ikeno<sup>68</sup>, Y. Ilchenko<sup>11,x</sup>, D. Iliadis<sup>157</sup>, N. Ilic<sup>146</sup>, T. Ince<sup>102</sup>, G. Introzzi<sup>122a,122b</sup>, P. Ioannou<sup>9,\*</sup>, M. Iodice<sup>135a</sup>, K. Iordanidou<sup>37</sup>, V. Ippolito<sup>58</sup>, N. Ishijima<sup>119</sup>, M. Ishino<sup>158</sup>, M. Ishitsuka<sup>160</sup>, R. Ishmukhametov<sup>112</sup>, C. Issever<sup>121</sup>, S. Istin<sup>20a</sup>, F. Ito<sup>165</sup>, J.M. Iturbe Ponce<sup>86</sup>, R. Iuppa<sup>163a,163b</sup>, W. Iwanski<sup>64</sup>, H. Iwasaki<sup>68</sup>, J.M. Izen<sup>43</sup>, V. Izzo<sup>105a</sup>, S. Jabbar<sup>3</sup>, B. Jackson<sup>123</sup>, P. Jackson<sup>1</sup>, V. Jain<sup>2</sup>, K.B. Jakobi<sup>85</sup>, K. Jakobs<sup>50</sup>, S. Jakobsen<sup>32</sup>, T. Jakoubek<sup>128</sup>, D.O. Jamin<sup>115</sup>, D.K. Jana<sup>81</sup>, R. Jansky<sup>64</sup>, J. Janssen<sup>23</sup>, M. Janus<sup>56</sup>, G. Jarlskog<sup>83</sup>, N. Javadov<sup>67,b</sup>, T. Javůrek<sup>50</sup>, F. Jeanneau<sup>137</sup>, L. Jeanty<sup>16</sup>, G.-Y. Jeng<sup>153</sup>, D. Jennens<sup>90</sup>, P. Jenni<sup>50,y</sup>, C. Jeske<sup>174</sup>, S. Jézéquel<sup>5</sup>, H. Ji<sup>177</sup>, J. Jia<sup>151</sup>, H. Jiang<sup>66</sup>, Y. Jiang<sup>59</sup>, S. Jiggins<sup>80</sup>, J. Jimenez Pena<sup>171</sup>, S. Jin<sup>35a</sup>, A. Jinaru<sup>28b</sup>, O. Jinnouchi<sup>160</sup>, H. Jivan<sup>148c</sup>, P. Johansson<sup>142</sup>, K.A. Johns<sup>7</sup>, W.J. Johnson<sup>139</sup>, K. Jon-And<sup>149a,149b</sup>, G. Jones<sup>174</sup>, R.W.L. Jones<sup>74</sup>, S. Jones<sup>7</sup>, T.J. Jones<sup>76</sup>, J. Jongmanns<sup>60a</sup>, P.M. Jorge<sup>127a,127b</sup>, J. Jovicevic<sup>164a</sup>, X. Ju<sup>177</sup>, A. Juste Rozas<sup>13,t</sup>, M.K. Köhler<sup>176</sup>, A. Kaczmarek<sup>41</sup>, M. Kado<sup>118</sup>, H. Kagan<sup>112</sup>, M. Kagan<sup>146</sup>, S.J. Kahn<sup>87</sup>, T. Kaji<sup>175</sup>, E. Kajomovitz<sup>47</sup>, C.W. Kalderon<sup>121</sup>, A. Kaluza<sup>85</sup>, S. Kama<sup>42</sup>, A. Kamenshchikov<sup>131</sup>, N. Kanaya<sup>158</sup>, S. Kaneti<sup>30</sup>, L. Kanjir<sup>77</sup>, V.A. Kantserov<sup>99</sup>, J. Kanzaki<sup>68</sup>, B. Kaplan<sup>111</sup>, L.S. Kaplan<sup>177</sup>, A. Kapliy<sup>33</sup>, D. Kar<sup>148c</sup>, K. Karakostas<sup>10</sup>, A. Karamaoun<sup>3</sup>, N. Karastathis<sup>10</sup>, M.J. Kareem<sup>56</sup>, E. Karentzos<sup>10</sup>, M. Karnevskiy<sup>85</sup>, S.N. Karpov<sup>67</sup>, Z.M. Karpova<sup>67</sup>, K. Karthik<sup>111</sup>, V. Kartvelishvili<sup>74</sup>, A.N. Karyukhin<sup>131</sup>, K. Kasahara<sup>165</sup>, L. Kashif<sup>177</sup>, R.D. Kass<sup>112</sup>, A. Kastanas<sup>150</sup>, Y. Kataoka<sup>158</sup>, C. Kato<sup>158</sup>, A. Katre<sup>51</sup>, J. Katzy<sup>44</sup>, K. Kawade<sup>104</sup>, K. Kawagoe<sup>72</sup>, T. Kawamoto<sup>158</sup>, G. Kawamura<sup>56</sup>, V.F. Kazanin<sup>110,c</sup>, R. Keeler<sup>173</sup>, R. Kehoe<sup>42</sup>, J.S. Keller<sup>44</sup>, J.J. Kempster<sup>79</sup>, H. Keoshkerian<sup>162</sup>, O. Kepka<sup>128</sup>, B.P. Kerševan<sup>77</sup>, S. Kersten<sup>179</sup>, R.A. Keyes<sup>89</sup>, M. Khader<sup>170</sup>, F. Khalil-zada<sup>12</sup>, A. Khanov<sup>115</sup>, A.G. Kharlamov<sup>110,c</sup>, T. Kharlamova<sup>110</sup>, T.J. Khoo<sup>51</sup>, V. Khovanskij<sup>98</sup>, E. Khramov<sup>67</sup>, J. Khubua<sup>53b,z</sup>, S. Kido<sup>69</sup>, C.R. Kilby<sup>79</sup>, H.Y. Kim<sup>8</sup>, S.H. Kim<sup>165</sup>, Y.K. Kim<sup>33</sup>, N. Kimura<sup>157</sup>, O.M. Kind<sup>17</sup>, B.T. King<sup>76</sup>, M. King<sup>171</sup>, J. Kirk<sup>132</sup>, A.E. Kiryunin<sup>102</sup>, T. Kishimoto<sup>158</sup>, D. Kisielewska<sup>40a</sup>, F. Kiss<sup>50</sup>, K. Kiuchi<sup>165</sup>, O. Kivernyik<sup>137</sup>, E. Kladiva<sup>147b</sup>, M.H. Klein<sup>37</sup>, M. Klein<sup>76</sup>, U. Klein<sup>76</sup>, K. Kleinknecht<sup>85</sup>, P. Klimek<sup>109</sup>, A. Klimentov<sup>27</sup>, R. Klingenberg<sup>45</sup>, J.A. Klinger<sup>142</sup>, T. Klioutchnikova<sup>32</sup>, E.-E. Kluge<sup>60a</sup>, P. Kluit<sup>108</sup>, S. Kluth<sup>102</sup>, J. Knapik<sup>41</sup>, E. Kneringer<sup>64</sup>, E.B.F.G. Knoops<sup>87</sup>, A. Knue<sup>55</sup>, A. Kobayashi<sup>158</sup>, D. Kobayashi<sup>160</sup>, T. Kobayashi<sup>158</sup>, M. Kobel<sup>46</sup>, M. Kocian<sup>146</sup>, P. Kodys<sup>130</sup>, N.M. Koehler<sup>102</sup>, T. Koffas<sup>31</sup>, E. Koffeman<sup>108</sup>, T. Koi<sup>146</sup>, H. Kolanoski<sup>17</sup>, M. Kolb<sup>60b</sup>, I. Koletsou<sup>5</sup>, A.A. Komar<sup>97,\*</sup>, Y. Komori<sup>158</sup>, T. Kondo<sup>68</sup>, N. Kondrashova<sup>44</sup>, K. Köneke<sup>50</sup>, A.C. König<sup>107</sup>, T. Kono<sup>68,aa</sup>, R. Konoplich<sup>111,ab</sup>, N. Konstantinidis<sup>80</sup>, R. Kopeliansky<sup>63</sup>, S. Koperny<sup>40a</sup>, L. Köpke<sup>85</sup>, A.K. Kopp<sup>50</sup>, K. Korcyl<sup>41</sup>, K. Kordas<sup>157</sup>, A. Korn<sup>80</sup>, A.A. Korol<sup>110,c</sup>, I. Korolkov<sup>13</sup>, E.V. Korolkova<sup>142</sup>, O. Kortner<sup>102</sup>, S. Kortner<sup>102</sup>, T. Kosek<sup>130</sup>, V.V. Kostyukhin<sup>23</sup>, A. Kotwal<sup>47</sup>, A. Koulouris<sup>10</sup>, A. Kourkoumeli-Charalampidi<sup>122a,122b</sup>, C. Kourkoumelis<sup>9</sup>, V. Kouskoura<sup>27</sup>, A.B. Kowalewska<sup>41</sup>, R. Kowalewski<sup>173</sup>, T.Z. Kowalski<sup>40a</sup>, C. Kozakai<sup>158</sup>, W. Kozanecki<sup>137</sup>, A.S. Kozhin<sup>131</sup>, V.A. Kramarenko<sup>100</sup>, G. Kramberger<sup>77</sup>, D. Krasnopevtsev<sup>99</sup>, M.W. Krasny<sup>82</sup>, A. Krasznahorkay<sup>32</sup>, A. Kravchenko<sup>27</sup>, M. Kretz<sup>60c</sup>, J. Kretzschmar<sup>76</sup>, K. Kreutzfeldt<sup>54</sup>,

P. Krieger<sup>162</sup>, K. Krizka<sup>33</sup>, K. Kroeninger<sup>45</sup>, H. Kroha<sup>102</sup>, J. Kroll<sup>123</sup>, J. Kroseberg<sup>23</sup>, J. Krstic<sup>14</sup>, U. Kruchonak<sup>67</sup>, H. Krüger<sup>23</sup>, N. Krumnack<sup>66</sup>, M.C. Kruse<sup>47</sup>, M. Kruskal<sup>24</sup>, T. Kubota<sup>90</sup>, H. Kucuk<sup>80</sup>, S. Kuday<sup>4b</sup>, J.T. Kuechler<sup>179</sup>, S. Kuehn<sup>50</sup>, A. Kugel<sup>60c</sup>, F. Kuger<sup>178</sup>, A. Kuhl<sup>138</sup>, T. Kuhl<sup>44</sup>, V. Kukhtin<sup>67</sup>, R. Kukla<sup>137</sup>, Y. Kulchitsky<sup>94</sup>, S. Kuleshov<sup>34b</sup>, M. Kuna<sup>133a,133b</sup>, T. Kunigo<sup>70</sup>, A. Kupco<sup>128</sup>, H. Kurashige<sup>69</sup>, Y.A. Kurochkin<sup>94</sup>, V. Kus<sup>128</sup>, E.S. Kuwertz<sup>173</sup>, M. Kuze<sup>160</sup>, J. Kvita<sup>116</sup>, T. Kwan<sup>173</sup>, D. Kyriazopoulos<sup>142</sup>, A. La Rosa<sup>102</sup>, J.L. La Rosa Navarro<sup>26d</sup>, L. La Rotonda<sup>39a,39b</sup>, C. Lacasta<sup>171</sup>, F. Lacava<sup>133a,133b</sup>, J. Lacey<sup>31</sup>, H. Lacker<sup>17</sup>, D. Lacour<sup>82</sup>, V.R. Lacuesta<sup>171</sup>, E. Ladygin<sup>67</sup>, R. Lafaye<sup>5</sup>, B. Laforge<sup>82</sup>, T. Lagouri<sup>180</sup>, S. Lai<sup>56</sup>, S. Lammers<sup>63</sup>, W. Lampl<sup>7</sup>, E. Lançon<sup>137</sup>, U. Landgraf<sup>50</sup>, M.P.J. Landon<sup>78</sup>, M.C. Lanfermann<sup>51</sup>, V.S. Lang<sup>60a</sup>, J.C. Lange<sup>13</sup>, A.J. Lankford<sup>167</sup>, F. Lanni<sup>27</sup>, K. Lantzsch<sup>23</sup>, A. Lanza<sup>122a</sup>, S. Laplace<sup>82</sup>, C. Lapoire<sup>32</sup>, J.F. Laporte<sup>137</sup>, T. Lari<sup>93a</sup>, F. Lasagni Manghi<sup>22a,22b</sup>, M. Lassnig<sup>32</sup>, P. Laurelli<sup>49</sup>, W. Lavrijsen<sup>16</sup>, A.T. Law<sup>138</sup>, P. Laycock<sup>76</sup>, T. Lazovich<sup>58</sup>, M. Lazzaroni<sup>93a,93b</sup>, B. Le<sup>90</sup>, O. Le Dortz<sup>82</sup>, E. Le Guirriec<sup>87</sup>, E.P. Le Quilleuc<sup>137</sup>, M. LeBlanc<sup>173</sup>, T. LeCompte<sup>6</sup>, F. Ledroit-Guillon<sup>57</sup>, C.A. Lee<sup>27</sup>, S.C. Lee<sup>154</sup>, L. Lee<sup>1</sup>, B. Lefebvre<sup>89</sup>, G. Lefebvre<sup>82</sup>, M. Lefebvre<sup>173</sup>, F. Legger<sup>101</sup>, C. Leggett<sup>16</sup>, A. Lehan<sup>76</sup>, G. Lehmann Miotto<sup>32</sup>, X. Lei<sup>7</sup>, W.A. Leight<sup>31</sup>, A. Leisos<sup>157,ac</sup>, A.G. Leister<sup>180</sup>, M.A.L. Leite<sup>26d</sup>, R. Leitner<sup>130</sup>, D. Lellouch<sup>176</sup>, B. Lemmer<sup>56</sup>, K.J.C. Leney<sup>80</sup>, T. Lenz<sup>23</sup>, B. Lenzi<sup>32</sup>, R. Leone<sup>7</sup>, S. Leone<sup>125a,125b</sup>, C. Leonidopoulos<sup>48</sup>, S. Leontsinis<sup>10</sup>, G. Lerner<sup>152</sup>, C. Leroy<sup>96</sup>, A.A.J. Lesage<sup>137</sup>, C.G. Lester<sup>30</sup>, M. Levchenko<sup>124</sup>, J. Levêque<sup>5</sup>, D. Levin<sup>91</sup>, L.J. Levinson<sup>176</sup>, M. Levy<sup>19</sup>, D. Lewis<sup>78</sup>, A.M. Leyko<sup>23</sup>, M. Leyton<sup>43</sup>, B. Li<sup>59,q</sup>, C. Li<sup>59</sup>, H. Li<sup>151</sup>, H.L. Li<sup>33</sup>, L. Li<sup>47</sup>, L. Li<sup>141</sup>, Q. Li<sup>35a</sup>, S. Li<sup>47</sup>, X. Li<sup>86</sup>, Y. Li<sup>144</sup>, Z. Liang<sup>35a</sup>, B. Liberti<sup>134a</sup>, A. Liblong<sup>162</sup>, P. Lichard<sup>32</sup>, K. Lie<sup>170</sup>, J. Liebal<sup>23</sup>, W. Liebig<sup>15</sup>, S. Liem<sup>108</sup>, A. Limosani<sup>153</sup>, S.C. Lin<sup>154,ad</sup>, T.H. Lin<sup>85</sup>, B.E. Lindquist<sup>151</sup>, A.E. Lioni<sup>51</sup>, E. Lipeles<sup>123</sup>, A. Lipniacka<sup>15</sup>, M. Lisovsky<sup>60b</sup>, T.M. Liss<sup>170</sup>, A. Lister<sup>172</sup>, A.M. Litke<sup>138</sup>, B. Liu<sup>154,ae</sup>, D. Liu<sup>154</sup>, H. Liu<sup>91</sup>, H. Liu<sup>27</sup>, J. Liu<sup>87</sup>, J.B. Liu<sup>59</sup>, K. Liu<sup>87</sup>, L. Liu<sup>170</sup>, M. Liu<sup>47</sup>, M. Liu<sup>59</sup>, Y.L. Liu<sup>59</sup>, Y. Liu<sup>59</sup>, M. Livan<sup>122a,122b</sup>, A. Lleres<sup>57</sup>, J. Llorente Merino<sup>35a</sup>, S.L. Lloyd<sup>78</sup>, F. Lo Sterzo<sup>154</sup>, E.M. Lobodzinska<sup>44</sup>, P. Loch<sup>7</sup>, F.K. Loebinger<sup>86</sup>, K.M. Loew<sup>25</sup>, A. Loginov<sup>180,\*</sup>, T. Lohse<sup>17</sup>, K. Lohwasser<sup>44</sup>, M. Lokajicek<sup>128</sup>, B.A. Long<sup>24</sup>, J.D. Long<sup>170</sup>, R.E. Long<sup>74</sup>, L. Longo<sup>75a,75b</sup>, K.A. Looper<sup>112</sup>, J.A. López<sup>34b</sup>, D. Lopez Mateos<sup>58</sup>, B. Lopez Paredes<sup>142</sup>, I. Lopez Paz<sup>13</sup>, A. Lopez Solis<sup>82</sup>, J. Lorenz<sup>101</sup>, N. Lorenzo Martinez<sup>63</sup>, M. Losada<sup>21</sup>, P.J. Lösel<sup>101</sup>, X. Lou<sup>35a</sup>, A. Lounis<sup>118</sup>, J. Love<sup>6</sup>, P.A. Love<sup>74</sup>, H. Lu<sup>62a</sup>, N. Lu<sup>91</sup>, H.J. Lubatti<sup>139</sup>, C. Luci<sup>133a,133b</sup>, A. Lucotte<sup>57</sup>, C. Luedtke<sup>50</sup>, F. Luehring<sup>63</sup>, W. Lukas<sup>64</sup>, L. Luminari<sup>133a</sup>, O. Lundberg<sup>149a,149b</sup>, B. Lund-Jensen<sup>150</sup>, P.M. Luzi<sup>82</sup>, D. Lynn<sup>27</sup>, R. Lysak<sup>128</sup>, E. Lytken<sup>83</sup>, V. Lyubushkin<sup>67</sup>, H. Ma<sup>27</sup>, L.L. Ma<sup>140</sup>, Y. Ma<sup>140</sup>, G. Maccarrone<sup>49</sup>, A. Macchiolo<sup>102</sup>, C.M. Macdonald<sup>142</sup>, B. Maček<sup>77</sup>, J. Machado Miguens<sup>123,127b</sup>, D. Madaffari<sup>87</sup>, R. Madar<sup>36</sup>, H.J. Maddocks<sup>169</sup>, W.F. Mader<sup>46</sup>, A. Madsen<sup>44</sup>, J. Maeda<sup>69</sup>, S. Maeland<sup>15</sup>, T. Maeno<sup>27</sup>, A. Maevskiy<sup>100</sup>, E. Magradze<sup>56</sup>, J. Mahlstedt<sup>108</sup>, C. Maiani<sup>118</sup>, C. Maidantchik<sup>26a</sup>, A.A. Maier<sup>102</sup>, T. Maier<sup>101</sup>, A. Maio<sup>127a,127b,127d</sup>, S. Majewski<sup>117</sup>, Y. Makida<sup>68</sup>, N. Makovec<sup>118</sup>, B. Malaescu<sup>82</sup>, Pa. Malecki<sup>41</sup>, V.P. Maleev<sup>124</sup>, F. Malek<sup>57</sup>, U. Mallik<sup>65</sup>, D. Malon<sup>6</sup>, C. Malone<sup>146</sup>, C. Malone<sup>30</sup>, S. Maltezos<sup>10</sup>, S. Malyukov<sup>32</sup>, J. Mamuzic<sup>171</sup>, G. Mancini<sup>49</sup>, L. Mandelli<sup>93a</sup>, I. Mandić<sup>77</sup>, J. Maneira<sup>127a,127b</sup>, L. Manhaes de Andrade Filho<sup>26b</sup>, J. Manjarres Ramos<sup>164b</sup>, A. Mann<sup>101</sup>, A. Manousos<sup>32</sup>, B. Mansoulie<sup>137</sup>, J.D. Mansour<sup>35a</sup>, R. Mantifel<sup>89</sup>, M. Mantoani<sup>56</sup>, S. Manzoni<sup>93a,93b</sup>, L. Mapelli<sup>32</sup>, G. Marceca<sup>29</sup>, L. March<sup>51</sup>, G. Marchiori<sup>82</sup>, M. Marcisovsky<sup>128</sup>, M. Marjanovic<sup>14</sup>, D.E. Marley<sup>91</sup>, F. Marroquim<sup>26a</sup>, S.P. Marsden<sup>86</sup>, Z. Marshall<sup>16</sup>, S. Marti-Garcia<sup>171</sup>, B. Martin<sup>92</sup>, T.A. Martin<sup>174</sup>, V.J. Martin<sup>48</sup>, B. Martin dit Latour<sup>15</sup>, M. Martinez<sup>13,t</sup>, V.I. Martinez Outschoorn<sup>170</sup>, S. Martin-Haugh<sup>132</sup>, V.S. Martoiu<sup>28b</sup>, A.C. Martyniuk<sup>80</sup>, A. Marzin<sup>32</sup>, L. Masetti<sup>85</sup>, T. Mashimo<sup>158</sup>, R. Mashinistov<sup>97</sup>, J. Masik<sup>86</sup>, A.L. Maslennikov<sup>110,c</sup>, I. Massa<sup>22a,22b</sup>, L. Massa<sup>22a,22b</sup>, P. Mastrandrea<sup>5</sup>, A. Mastroberardino<sup>39a,39b</sup>, T. Masubuchi<sup>158</sup>, P. Mättig<sup>179</sup>, J. Mattmann<sup>85</sup>, J. Maurer<sup>28b</sup>,

S.J. Maxfield<sup>76</sup>, D.A. Maximov<sup>110,c</sup>, R. Mazini<sup>154</sup>, I. Maznas<sup>157</sup>, S.M. Mazza<sup>93a,93b</sup>,  
N.C. Mc Fadden<sup>106</sup>, G. Mc Goldrick<sup>162</sup>, S.P. Mc Kee<sup>91</sup>, A. McCarn<sup>91</sup>, R.L. McCarthy<sup>151</sup>,  
T.G. McCarthy<sup>102</sup>, L.I. McClymont<sup>80</sup>, E.F. McDonald<sup>90</sup>, J.A. Mcfayden<sup>80</sup>, G. Mchedlidze<sup>56</sup>,  
S.J. McMahon<sup>132</sup>, R.A. McPherson<sup>173,n</sup>, M. Medinnis<sup>44</sup>, S. Meehan<sup>139</sup>, S. Mehlhase<sup>101</sup>,  
A. Mehta<sup>76</sup>, K. Meier<sup>60a</sup>, C. Meineck<sup>101</sup>, B. Meirose<sup>43</sup>, D. Melini<sup>171</sup>, B.R. Mellado Garcia<sup>148c</sup>,  
M. Melo<sup>147a</sup>, F. Meloni<sup>18</sup>, A. Mengarelli<sup>22a,22b</sup>, S. Menke<sup>102</sup>, E. Meoni<sup>166</sup>, S. Mergelmeyer<sup>17</sup>,  
P. Mermod<sup>51</sup>, L. Merola<sup>105a,105b</sup>, C. Meroni<sup>93a</sup>, F.S. Merritt<sup>33</sup>, A. Messina<sup>133a,133b</sup>, J. Metcalfe<sup>6</sup>,  
A.S. Mete<sup>167</sup>, C. Meyer<sup>85</sup>, C. Meyer<sup>123</sup>, J-P. Meyer<sup>137</sup>, J. Meyer<sup>108</sup>, H. Meyer Zu Theenhausen<sup>60a</sup>,  
F. Miano<sup>152</sup>, R.P. Middleton<sup>132</sup>, S. Miglioranza<sup>52a,52b</sup>, L. Mijović<sup>48</sup>, G. Mikenberg<sup>176</sup>,  
M. Mikestikova<sup>128</sup>, M. Mikuž<sup>77</sup>, M. Milesi<sup>90</sup>, A. Milic<sup>64</sup>, D.W. Miller<sup>33</sup>, C. Mills<sup>48</sup>, A. Milov<sup>176</sup>,  
D.A. Milstead<sup>149a,149b</sup>, A.A. Minaenko<sup>131</sup>, Y. Minami<sup>158</sup>, I.A. Minashvili<sup>67</sup>, A.I. Mincer<sup>111</sup>,  
B. Mindur<sup>40a</sup>, M. Mineev<sup>67</sup>, Y. Minegishi<sup>158</sup>, Y. Ming<sup>177</sup>, L.M. Mir<sup>13</sup>, K.P. Mistry<sup>123</sup>,  
T. Mitani<sup>175</sup>, J. Mitrevski<sup>101</sup>, V.A. Mitsou<sup>171</sup>, A. Miucci<sup>18</sup>, P.S. Miyagawa<sup>142</sup>, J.U. Mjörnmark<sup>83</sup>,  
M. Mlynarikova<sup>130</sup>, T. Moa<sup>149a,149b</sup>, K. Mochizuki<sup>96</sup>, S. Mohapatra<sup>37</sup>, S. Molander<sup>149a,149b</sup>,  
R. Moles-Valls<sup>23</sup>, R. Monden<sup>70</sup>, M.C. Mondragon<sup>92</sup>, K. Mönig<sup>44</sup>, J. Monk<sup>38</sup>, E. Monnier<sup>87</sup>,  
A. Montalbano<sup>151</sup>, J. Montejo Berlingen<sup>32</sup>, F. Monticelli<sup>73</sup>, S. Monzani<sup>93a,93b</sup>, R.W. Moore<sup>3</sup>,  
N. Morange<sup>118</sup>, D. Moreno<sup>21</sup>, M. Moreno Llácer<sup>56</sup>, P. Morettini<sup>52a</sup>, S. Morgenstern<sup>32</sup>, D. Mori<sup>145</sup>,  
T. Mori<sup>158</sup>, M. Morii<sup>58</sup>, M. Morinaga<sup>158</sup>, V. Morisbak<sup>120</sup>, S. Moritz<sup>85</sup>, A.K. Morley<sup>153</sup>,  
G. Mornacchi<sup>32</sup>, J.D. Morris<sup>78</sup>, S.S. Mortensen<sup>38</sup>, L. Morvaj<sup>151</sup>, M. Mosidze<sup>53b</sup>, J. Moss<sup>146,af</sup>,  
K. Motohashi<sup>160</sup>, R. Mount<sup>146</sup>, E. Mountricha<sup>27</sup>, E.J.W. Moyse<sup>88</sup>, S. Muanza<sup>87</sup>, R.D. Mudd<sup>19</sup>,  
F. Mueller<sup>102</sup>, J. Mueller<sup>126</sup>, R.S.P. Mueller<sup>101</sup>, T. Mueller<sup>30</sup>, D. Muenstermann<sup>74</sup>, P. Mullen<sup>55</sup>,  
G.A. Mullier<sup>18</sup>, F.J. Munoz Sanchez<sup>86</sup>, J.A. Murillo Quijada<sup>19</sup>, W.J. Murray<sup>174,132</sup>,  
H. Musheghyan<sup>56</sup>, M. Muškinja<sup>77</sup>, A.G. Myagkov<sup>131,ag</sup>, M. Myska<sup>129</sup>, B.P. Nachman<sup>146</sup>,  
O. Nackenhorst<sup>51</sup>, K. Nagai<sup>121</sup>, R. Nagai<sup>68,aa</sup>, K. Nagano<sup>68</sup>, Y. Nagasaka<sup>61</sup>, K. Nagata<sup>165</sup>,  
M. Nagel<sup>50</sup>, E. Nagy<sup>87</sup>, A.M. Nairz<sup>32</sup>, Y. Nakahama<sup>104</sup>, K. Nakamura<sup>68</sup>, T. Nakamura<sup>158</sup>,  
I. Nakano<sup>113</sup>, R.F. Naranjo Garcia<sup>44</sup>, R. Narayan<sup>11</sup>, D.I. Narrias Villar<sup>60a</sup>, I. Naryshkin<sup>124</sup>,  
T. Naumann<sup>44</sup>, G. Navarro<sup>21</sup>, R. Nayyar<sup>7</sup>, H.A. Neal<sup>91</sup>, P.Yu. Nechaeva<sup>97</sup>, T.J. Neep<sup>86</sup>,  
A. Negri<sup>122a,122b</sup>, M. Negrini<sup>22a</sup>, S. Nektarijevic<sup>107</sup>, C. Nellist<sup>118</sup>, A. Nelson<sup>167</sup>, S. Nemecek<sup>128</sup>,  
P. Nemethy<sup>111</sup>, A.A. Nepomuceno<sup>26a</sup>, M. Nessi<sup>32,ah</sup>, M.S. Neubauer<sup>170</sup>, M. Neumann<sup>179</sup>,  
R.M. Neves<sup>111</sup>, P. Nevski<sup>27</sup>, P.R. Newman<sup>19</sup>, D.H. Nguyen<sup>6</sup>, T. Nguyen Manh<sup>96</sup>,  
R.B. Nickerson<sup>121</sup>, R. Nicolaidou<sup>137</sup>, J. Nielsen<sup>138</sup>, A. Nikiforov<sup>17</sup>, V. Nikolaenko<sup>131,ag</sup>,  
I. Nikolic-Audit<sup>82</sup>, K. Nikolopoulos<sup>19</sup>, J.K. Nilsen<sup>120</sup>, P. Nilsson<sup>27</sup>, Y. Ninomiya<sup>158</sup>, A. Nisati<sup>133a</sup>,  
R. Nisius<sup>102</sup>, T. Nobe<sup>158</sup>, M. Nomachi<sup>119</sup>, I. Nomidis<sup>31</sup>, T. Nooney<sup>78</sup>, S. Norberg<sup>114</sup>,  
M. Nordberg<sup>32</sup>, N. Norjoharuddeen<sup>121</sup>, O. Novgorodova<sup>46</sup>, S. Nowak<sup>102</sup>, M. Nozaki<sup>68</sup>,  
L. Nozka<sup>116</sup>, K. Ntekas<sup>167</sup>, E. Nurse<sup>80</sup>, F. Nuti<sup>90</sup>, F. O'grady<sup>7</sup>, D.C. O'Neil<sup>145</sup>, A.A. O'Rourke<sup>44</sup>,  
V. O'Shea<sup>55</sup>, F.G. Oakham<sup>31,d</sup>, H. Oberlack<sup>102</sup>, T. Obermann<sup>23</sup>, J. Ocariz<sup>82</sup>, A. Ochi<sup>69</sup>,  
I. Ochoa<sup>37</sup>, J.P. Ochoa-Ricoux<sup>34a</sup>, S. Oda<sup>72</sup>, S. Odaka<sup>68</sup>, H. Ogren<sup>63</sup>, A. Oh<sup>86</sup>, S.H. Oh<sup>47</sup>,  
C.C. Ohm<sup>16</sup>, H. Ohman<sup>169</sup>, H. Oide<sup>52a,52b</sup>, H. Okawa<sup>165</sup>, Y. Okumura<sup>158</sup>, T. Okuyama<sup>68</sup>,  
A. Olariu<sup>28b</sup>, L.F. Oleiro Seabra<sup>127a</sup>, S.A. Olivares Pino<sup>48</sup>, D. Oliveira Damazio<sup>27</sup>, A. Olszewski<sup>41</sup>,  
J. Olszowska<sup>41</sup>, A. Onofre<sup>127a,127e</sup>, K. Onogi<sup>104</sup>, P.U.E. Onyisi<sup>11,x</sup>, M.J. Oreglia<sup>33</sup>, Y. Oren<sup>156</sup>,  
D. Orestano<sup>135a,135b</sup>, N. Orlando<sup>62b</sup>, R.S. Orr<sup>162</sup>, B. Osculati<sup>52a,52b,\*</sup>, R. Ospanov<sup>86</sup>,  
G. Otero y Garzon<sup>29</sup>, H. Otono<sup>72</sup>, M. Ouchrif<sup>136d</sup>, F. Ould-Saada<sup>120</sup>, A. Ouraou<sup>137</sup>,  
K.P. Oussoren<sup>108</sup>, Q. Ouyang<sup>35a</sup>, M. Owen<sup>55</sup>, R.E. Owen<sup>19</sup>, V.E. Ozcan<sup>20a</sup>, N. Ozturk<sup>8</sup>,  
K. Pachal<sup>145</sup>, A. Pacheco Pages<sup>13</sup>, L. Pacheco Rodriguez<sup>137</sup>, C. Padilla Aranda<sup>13</sup>, M. Pagáčová<sup>50</sup>,  
S. Pagan Griso<sup>16</sup>, M. Paganini<sup>180</sup>, F. Paige<sup>27</sup>, P. Pais<sup>88</sup>, K. Pajchel<sup>120</sup>, G. Palacino<sup>164b</sup>,  
S. Palazzo<sup>39a,39b</sup>, S. Palestini<sup>32</sup>, M. Palka<sup>40b</sup>, D. Pallin<sup>36</sup>, E.St. Panagiotopoulou<sup>10</sup>,  
C.E. Pandini<sup>82</sup>, J.G. Panduro Vazquez<sup>79</sup>, P. Pani<sup>149a,149b</sup>, S. Panitkin<sup>27</sup>, D. Pantea<sup>28b</sup>,  
L. Paolozzi<sup>51</sup>, Th.D. Papadopoulou<sup>10</sup>, K. Papageorgiou<sup>157</sup>, A. Paramonov<sup>6</sup>,

D. Paredes Hernandez<sup>180</sup>, A.J. Parker<sup>74</sup>, M.A. Parker<sup>30</sup>, K.A. Parker<sup>142</sup>, F. Parodi<sup>52a,52b</sup>, J.A. Parsons<sup>37</sup>, U. Parzefall<sup>50</sup>, V.R. Pascuzzi<sup>162</sup>, E. Pasqualucci<sup>133a</sup>, S. Passaggio<sup>52a</sup>, Fr. Pastore<sup>79</sup>, G. Pásztor<sup>31,ai</sup>, S. Pataria<sup>179</sup>, J.R. Pater<sup>86</sup>, T. Pauly<sup>32</sup>, J. Pearce<sup>173</sup>, B. Pearson<sup>114</sup>, L.E. Pedersen<sup>38</sup>, M. Pedersen<sup>120</sup>, S. Pedraza Lopez<sup>171</sup>, R. Pedro<sup>127a,127b</sup>, S.V. Peleganchuk<sup>110,c</sup>, O. Penc<sup>128</sup>, C. Peng<sup>35a</sup>, H. Peng<sup>59</sup>, J. Penwell<sup>63</sup>, B.S. Peralva<sup>26b</sup>, M.M. Perego<sup>137</sup>, D.V. Perepelitsa<sup>27</sup>, E. Perez Codina<sup>164a</sup>, L. Perini<sup>93a,93b</sup>, H. Pernegger<sup>32</sup>, S. Perrella<sup>105a,105b</sup>, R. Peschke<sup>44</sup>, V.D. Peshekhonov<sup>67</sup>, K. Peters<sup>44</sup>, R.F.Y. Peters<sup>86</sup>, B.A. Petersen<sup>32</sup>, T.C. Petersen<sup>38</sup>, E. Petit<sup>57</sup>, A. Petridis<sup>1</sup>, C. Petridou<sup>157</sup>, P. Petroff<sup>118</sup>, E. Petrolo<sup>133a</sup>, M. Petrov<sup>121</sup>, F. Petrucci<sup>135a,135b</sup>, N.E. Pettersson<sup>88</sup>, A. Peyaud<sup>137</sup>, R. Pezoa<sup>34b</sup>, P.W. Phillips<sup>132</sup>, G. Piacquadio<sup>146,aj</sup>, E. Pianori<sup>174</sup>, A. Picazio<sup>88</sup>, E. Piccaro<sup>78</sup>, M. Piccinini<sup>22a,22b</sup>, M.A. Pickering<sup>121</sup>, R. Piegai<sup>29</sup>, J.E. Pilcher<sup>33</sup>, A.D. Pilkington<sup>86</sup>, A.W.J. Pin<sup>86</sup>, M. Pinamonti<sup>168a,168c,ak</sup>, J.L. Pinfold<sup>3</sup>, A. Pingel<sup>38</sup>, S. Pires<sup>82</sup>, H. Pirumov<sup>44</sup>, M. Pitt<sup>176</sup>, L. Plazak<sup>147a</sup>, M.-A. Pleier<sup>27</sup>, V. Pleskot<sup>85</sup>, E. Plotnikova<sup>67</sup>, P. Plucinski<sup>92</sup>, D. Pluth<sup>66</sup>, R. Poettgen<sup>149a,149b</sup>, L. Poggioli<sup>118</sup>, D. Pohl<sup>23</sup>, G. Polesello<sup>122a</sup>, A. Poley<sup>44</sup>, A. Policicchio<sup>39a,39b</sup>, R. Polifka<sup>162</sup>, A. Polini<sup>22a</sup>, C.S. Pollard<sup>55</sup>, V. Polychronakos<sup>27</sup>, K. Pommès<sup>32</sup>, L. Pontecorvo<sup>133a</sup>, B.G. Pope<sup>92</sup>, G.A. Popeneciu<sup>28c</sup>, A. Poppleton<sup>32</sup>, S. Pospisil<sup>129</sup>, K. Potamianos<sup>16</sup>, I.N. Potrap<sup>67</sup>, C.J. Potter<sup>30</sup>, C.T. Potter<sup>117</sup>, G. Poulard<sup>32</sup>, J. Poveda<sup>32</sup>, V. Pozdnyakov<sup>67</sup>, M.E. Pozo Astigarraga<sup>32</sup>, P. Pralavorio<sup>87</sup>, A. Pranko<sup>16</sup>, S. Prell<sup>66</sup>, D. Price<sup>86</sup>, L.E. Price<sup>6</sup>, M. Primavera<sup>75a</sup>, S. Prince<sup>89</sup>, K. Prokofiev<sup>62c</sup>, F. Prokoshin<sup>34b</sup>, S. Protopopescu<sup>27</sup>, J. Proudfoot<sup>6</sup>, M. Przybycien<sup>40a</sup>, D. Puddu<sup>135a,135b</sup>, M. Purohit<sup>27,al</sup>, P. Puzo<sup>118</sup>, J. Qian<sup>91</sup>, G. Qin<sup>55</sup>, Y. Qin<sup>86</sup>, A. Quadt<sup>56</sup>, W.B. Quayle<sup>168a,168b</sup>, M. Queitsch-Maitland<sup>86</sup>, D. Quilty<sup>55</sup>, S. Raddum<sup>120</sup>, V. Radeka<sup>27</sup>, V. Radescu<sup>121</sup>, S.K. Radhakrishnan<sup>151</sup>, P. Radloff<sup>117</sup>, P. Rados<sup>90</sup>, F. Ragusa<sup>93a,93b</sup>, G. Rahal<sup>182</sup>, J.A. Raine<sup>86</sup>, S. Rajagopalan<sup>27</sup>, M. Rammensee<sup>32</sup>, C. Rangel-Smith<sup>169</sup>, M.G. Ratti<sup>93a,93b</sup>, D.M. Rauch<sup>44</sup>, F. Rauscher<sup>101</sup>, S. Rave<sup>85</sup>, T. Ravenscroft<sup>55</sup>, I. Ravinovich<sup>176</sup>, M. Raymond<sup>32</sup>, A.L. Read<sup>120</sup>, N.P. Readioff<sup>76</sup>, M. Reale<sup>75a,75b</sup>, D.M. Rebuzzi<sup>122a,122b</sup>, A. Redelbach<sup>178</sup>, G. Redlinger<sup>27</sup>, R. Reece<sup>138</sup>, R.G. Reed<sup>148c</sup>, K. Reeves<sup>43</sup>, L. Rehnisch<sup>17</sup>, J. Reichert<sup>123</sup>, A. Reiss<sup>85</sup>, C. Rembser<sup>32</sup>, H. Ren<sup>35a</sup>, M. Rescigno<sup>133a</sup>, S. Resconi<sup>93a</sup>, O.L. Rezanova<sup>110,c</sup>, P. Reznicek<sup>130</sup>, R. Rezvani<sup>96</sup>, R. Richter<sup>102</sup>, S. Richter<sup>80</sup>, E. Richter-Was<sup>40b</sup>, O. Ricken<sup>23</sup>, M. Ridel<sup>82</sup>, P. Rieck<sup>17</sup>, C.J. Riegel<sup>179</sup>, J. Rieger<sup>56</sup>, O. Rifki<sup>114</sup>, M. Rijssenbeek<sup>151</sup>, A. Rimoldi<sup>122a,122b</sup>, M. Rimoldi<sup>18</sup>, L. Rinaldi<sup>22a</sup>, B. Ristić<sup>51</sup>, E. Ritsch<sup>32</sup>, I. Riu<sup>13</sup>, F. Rizatdinova<sup>115</sup>, E. Rizvi<sup>78</sup>, C. Rizzi<sup>13</sup>, S.H. Robertson<sup>89,n</sup>, A. Robichaud-Veronneau<sup>89</sup>, D. Robinson<sup>30</sup>, J.E.M. Robinson<sup>44</sup>, A. Robson<sup>55</sup>, C. Roda<sup>125a,125b</sup>, Y. Rodina<sup>87</sup>, A. Rodriguez Perez<sup>13</sup>, D. Rodriguez Rodriguez<sup>171</sup>, S. Roe<sup>32</sup>, C.S. Rogan<sup>58</sup>, O. Røhne<sup>120</sup>, A. Romaniouk<sup>99</sup>, M. Romano<sup>22a,22b</sup>, S.M. Romano Saez<sup>36</sup>, E. Romero Adam<sup>171</sup>, N. Rompotis<sup>139</sup>, M. Ronzani<sup>50</sup>, L. Roos<sup>82</sup>, E. Ros<sup>171</sup>, S. Rosati<sup>133a</sup>, K. Rosbach<sup>50</sup>, P. Rose<sup>138</sup>, N.-A. Rosien<sup>56</sup>, V. Rossetti<sup>149a,149b</sup>, E. Rossi<sup>105a,105b</sup>, L.P. Rossi<sup>52a</sup>, J.H.N. Rosten<sup>30</sup>, R. Rosten<sup>139</sup>, M. Rotaru<sup>28b</sup>, I. Roth<sup>176</sup>, J. Rothberg<sup>139</sup>, D. Rousseau<sup>118</sup>, A. Rozanov<sup>87</sup>, Y. Rozen<sup>155</sup>, X. Ruan<sup>148c</sup>, F. Rubbo<sup>146</sup>, M.S. Rudolph<sup>162</sup>, F. Rühr<sup>50</sup>, R. Ruiz de Austri<sup>am</sup>, A. Ruiz-Martinez<sup>31</sup>, Z. Rurikova<sup>50</sup>, N.A. Rusakovich<sup>67</sup>, A. Ruschke<sup>101</sup>, H.L. Russell<sup>139</sup>, J.P. Rutherford<sup>7</sup>, N. Ruthmann<sup>32</sup>, Y.F. Ryabov<sup>124</sup>, M. Rybar<sup>170</sup>, G. Rybkin<sup>118</sup>, S. Ryu<sup>6</sup>, A. Ryzhov<sup>131</sup>, G.F. Rzehorz<sup>56</sup>, A.F. Saavedra<sup>153</sup>, G. Sabato<sup>108</sup>, S. Sacerdoti<sup>29</sup>, H.F.-W. Sadrozinski<sup>138</sup>, R. Sadykov<sup>67</sup>, F. Safai Tehrani<sup>133a</sup>, P. Saha<sup>109</sup>, M. Sahinsoy<sup>60a</sup>, M. Saimpert<sup>137</sup>, T. Saito<sup>158</sup>, H. Sakamoto<sup>158</sup>, Y. Sakurai<sup>175</sup>, G. Salamanna<sup>135a,135b</sup>, A. Salamon<sup>134a,134b</sup>, J.E. Salazar Loyola<sup>34b</sup>, D. Salek<sup>108</sup>, P.H. Sales De Bruin<sup>139</sup>, D. Salihagic<sup>102</sup>, A. Salnikov<sup>146</sup>, J. Salt<sup>171</sup>, D. Salvatore<sup>39a,39b</sup>, F. Salvatore<sup>152</sup>, A. Salvucci<sup>62a,62b,62c</sup>, A. Salzburger<sup>32</sup>, D. Sammel<sup>50</sup>, D. Sampsonidis<sup>157</sup>, A. Sanchez<sup>105a,105b</sup>, J. Sánchez<sup>171</sup>, V. Sanchez Martinez<sup>171</sup>, H. Sandaker<sup>120</sup>, R.L. Sandbach<sup>78</sup>, M. Sandhoff<sup>179</sup>, C. Sandovai<sup>21</sup>, D.P.C. Sankey<sup>132</sup>, M. Sannino<sup>52a,52b</sup>, A. Sansoni<sup>49</sup>, C. Santoni<sup>36</sup>, R. Santonico<sup>134a,134b</sup>,

H. Santos<sup>127a</sup>, I. Santoyo Castillo<sup>152</sup>, K. Sapp<sup>126</sup>, A. Saponov<sup>67</sup>, J.G. Saraiva<sup>127a,127d</sup>,  
 B. Sarrazin<sup>23</sup>, O. Sasaki<sup>68</sup>, K. Sato<sup>165</sup>, E. Sauvan<sup>5</sup>, G. Savage<sup>79</sup>, P. Savard<sup>162,d</sup>, N. Savic<sup>102</sup>,  
 C. Sawyer<sup>132</sup>, L. Sawyer<sup>81,s</sup>, J. Saxon<sup>33</sup>, C. Sbarra<sup>22a</sup>, A. Sbrizzi<sup>22a,22b</sup>, T. Scanlon<sup>80</sup>,  
 D.A. Scannicchio<sup>167</sup>, M. Scarcella<sup>153</sup>, V. Scarfone<sup>39a,39b</sup>, J. Schaarschmidt<sup>176</sup>, P. Schacht<sup>102</sup>,  
 B.M. Schachtner<sup>101</sup>, D. Schaefer<sup>32</sup>, L. Schaefer<sup>123</sup>, R. Schaefer<sup>44</sup>, J. Schaeffer<sup>85</sup>, S. Schaepe<sup>23</sup>,  
 S. Schaetzel<sup>60b</sup>, U. Schäfer<sup>85</sup>, A.C. Schaffer<sup>118</sup>, D. Schaile<sup>101</sup>, R.D. Schamberger<sup>151</sup>, V. Scharf<sup>60a</sup>,  
 V.A. Schegelsky<sup>124</sup>, D. Scheirich<sup>130</sup>, M. Schernau<sup>167</sup>, C. Schiavi<sup>52a,52b</sup>, S. Schier<sup>138</sup>, C. Schillo<sup>50</sup>,  
 M. Schioppa<sup>39a,39b</sup>, S. Schlenker<sup>32</sup>, K.R. Schmidt-Sommerfeld<sup>102</sup>, K. Schmieden<sup>32</sup>, C. Schmitt<sup>85</sup>,  
 S. Schmitt<sup>44</sup>, S. Schmitz<sup>85</sup>, B. Schneider<sup>164a</sup>, U. Schnoor<sup>50</sup>, L. Schoeffel<sup>137</sup>, A. Schoening<sup>60b</sup>,  
 B.D. Schoenrock<sup>92</sup>, E. Schopf<sup>23</sup>, M. Schott<sup>85</sup>, J.F.P. Schouwenberg<sup>107</sup>, J. Schovancova<sup>8</sup>,  
 S. Schramm<sup>51</sup>, M. Schreyer<sup>178</sup>, N. Schuh<sup>85</sup>, A. Schulte<sup>85</sup>, M.J. Schultens<sup>23</sup>,  
 H.-C. Schultz-Coulon<sup>60a</sup>, H. Schulz<sup>17</sup>, M. Schumacher<sup>50</sup>, B.A. Schumm<sup>138</sup>, Ph. Schune<sup>137</sup>,  
 A. Schwartzman<sup>146</sup>, T.A. Schwarz<sup>91</sup>, H. Schweiger<sup>86</sup>, Ph. Schwemling<sup>137</sup>, R. Schwienhorst<sup>92</sup>,  
 J. Schwindling<sup>137</sup>, T. Schwindt<sup>23</sup>, G. Sciolla<sup>25</sup>, F. Scuri<sup>125a,125b</sup>, F. Scutti<sup>90</sup>, J. Searcy<sup>91</sup>,  
 P. Seema<sup>23</sup>, S.C. Seidel<sup>106</sup>, A. Seiden<sup>138</sup>, F. Seifert<sup>129</sup>, J.M. Seixas<sup>26a</sup>, G. Sekhniaidze<sup>105a</sup>,  
 K. Sekhon<sup>91</sup>, S.J. Sekula<sup>42</sup>, D.M. Seliverstov<sup>124,\*</sup>, N. Semprini-Cesari<sup>22a,22b</sup>, C. Serfon<sup>120</sup>,  
 L. Serin<sup>118</sup>, L. Serkin<sup>168a,168b</sup>, M. Sessa<sup>135a,135b</sup>, R. Seuster<sup>173</sup>, H. Severini<sup>114</sup>, T. Sfiligoi<sup>77</sup>,  
 F. Sforza<sup>32</sup>, A. Sfyrila<sup>51</sup>, E. Shabalina<sup>56</sup>, N.W. Shaikh<sup>149a,149b</sup>, L.Y. Shan<sup>35a</sup>, R. Shang<sup>170</sup>,  
 J.T. Shank<sup>24</sup>, M. Shapiro<sup>16</sup>, P.B. Shatalov<sup>98</sup>, K. Shaw<sup>168a,168b</sup>, S.M. Shaw<sup>86</sup>,  
 A. Shcherbakova<sup>149a,149b</sup>, C.Y. Shehu<sup>152</sup>, P. Sherwood<sup>80</sup>, L. Shi<sup>154,an</sup>, S. Shimizu<sup>69</sup>,  
 C.O. Shimmin<sup>167</sup>, M. Shimojima<sup>103</sup>, S. Shirabe<sup>72</sup>, M. Shiyakova<sup>67,ao</sup>, A. Shmeleva<sup>97</sup>,  
 D. Shoaleh Saadi<sup>96</sup>, M.J. Shochet<sup>33</sup>, S. Shojaii<sup>93a,93b</sup>, D.R. Shope<sup>114</sup>, S. Shrestha<sup>112</sup>, E. Shulga<sup>99</sup>,  
 M.A. Shupe<sup>7</sup>, P. Sicho<sup>128</sup>, A.M. Sickles<sup>170</sup>, P.E. Sidebo<sup>150</sup>, O. Sidiropoulou<sup>178</sup>, D. Sidorov<sup>115</sup>,  
 A. Sidoti<sup>22a,22b</sup>, F. Siegert<sup>46</sup>, Dj. Sijacki<sup>14</sup>, J. Silva<sup>127a,127d</sup>, S.B. Silverstein<sup>149a</sup>, V. Simak<sup>129</sup>,  
 Lj. Simic<sup>14</sup>, S. Simion<sup>118</sup>, E. Simioni<sup>85</sup>, B. Simmons<sup>80</sup>, D. Simon<sup>36</sup>, M. Simon<sup>85</sup>, P. Sinervo<sup>162</sup>,  
 N.B. Sinev<sup>117</sup>, M. Sioli<sup>22a,22b</sup>, G. Siragusa<sup>178</sup>, S.Yu. Sivoklov<sup>100</sup>, J. Sjölin<sup>149a,149b</sup>,  
 M.B. Skinner<sup>74</sup>, H.P. Skottowe<sup>58</sup>, P. Skubic<sup>114</sup>, M. Slater<sup>19</sup>, T. Slavicek<sup>129</sup>, M. Slawinska<sup>108</sup>,  
 K. Sliwa<sup>166</sup>, R. Slovak<sup>130</sup>, V. Smakhtin<sup>176</sup>, B.H. Smart<sup>5</sup>, L. Smestad<sup>15</sup>, J. Smiesko<sup>147a</sup>,  
 S.Yu. Smirnov<sup>99</sup>, Y. Smirnov<sup>99</sup>, L.N. Smirnova<sup>100,ap</sup>, O. Smirnova<sup>83</sup>, M.N.K. Smith<sup>37</sup>,  
 R.W. Smith<sup>37</sup>, M. Smizanska<sup>74</sup>, K. Smolek<sup>129</sup>, A.A. Snesarev<sup>97</sup>, I.M. Snyder<sup>117</sup>, S. Snyder<sup>27</sup>,  
 R. Sobie<sup>173,n</sup>, F. Socher<sup>46</sup>, A. Soffer<sup>156</sup>, D.A. Soh<sup>154</sup>, G. Sokhrannyi<sup>77</sup>, C.A. Solans Sanchez<sup>32</sup>,  
 M. Solar<sup>129</sup>, E.Yu. Soldatov<sup>99</sup>, U. Soldevila<sup>171</sup>, A.A. Solodkov<sup>131</sup>, A. Soloshenko<sup>67</sup>,  
 O.V. Solovyanov<sup>131</sup>, V. Solovyev<sup>124</sup>, P. Sommer<sup>50</sup>, H. Son<sup>166</sup>, H.Y. Song<sup>59,aq</sup>, A. Sood<sup>16</sup>,  
 A. Sopczak<sup>129</sup>, V. Sopko<sup>129</sup>, V. Sorin<sup>13</sup>, D. Sosa<sup>60b</sup>, C.L. Sotiropoulou<sup>125a,125b</sup>, R. Soualah<sup>168a,168c</sup>,  
 A.M. Soukharev<sup>110,c</sup>, D. South<sup>44</sup>, B.C. Sowden<sup>79</sup>, S. Spagnolo<sup>75a,75b</sup>, M. Spalla<sup>125a,125b</sup>,  
 M. Spangenberg<sup>174</sup>, F. Spanò<sup>79</sup>, D. Sperlich<sup>17</sup>, F. Spettel<sup>102</sup>, R. Spighi<sup>22a</sup>, G. Spigo<sup>32</sup>,  
 L.A. Spiller<sup>90</sup>, M. Spousta<sup>130</sup>, R.D. St. Denis<sup>55,\*</sup>, A. Stabile<sup>93a</sup>, R. Stamen<sup>60a</sup>, S. Stamm<sup>17</sup>,  
 E. Stanecka<sup>41</sup>, R.W. Stanek<sup>6</sup>, C. Stanescu<sup>135a</sup>, M. Stanescu-Bellu<sup>44</sup>, M.M. Stanitzki<sup>44</sup>,  
 S. Stapnes<sup>120</sup>, E.A. Starchenko<sup>131</sup>, G.H. Stark<sup>33</sup>, J. Stark<sup>57</sup>, P. Staroba<sup>128</sup>, P. Starovoitov<sup>60a</sup>,  
 S. Stärz<sup>32</sup>, R. Staszewski<sup>41</sup>, P. Steinberg<sup>27</sup>, B. Stelzer<sup>145</sup>, H.J. Stelzer<sup>32</sup>, O. Stelzer-Chilton<sup>164a</sup>,  
 H. Stenzel<sup>54</sup>, G.A. Stewart<sup>55</sup>, J.A. Stillings<sup>23</sup>, M.C. Stockton<sup>89</sup>, M. Stoebe<sup>89</sup>, G. Stoicea<sup>28b</sup>,  
 P. Stolte<sup>56</sup>, S. Stonjek<sup>102</sup>, A.R. Stradling<sup>8</sup>, A. Straessner<sup>46</sup>, M.E. Stramaglia<sup>18</sup>, J. Strandberg<sup>150</sup>,  
 S. Strandberg<sup>149a,149b</sup>, A. Strandlie<sup>120</sup>, M. Strauss<sup>114</sup>, P. Strizenec<sup>147b</sup>, R. Ströhmer<sup>178</sup>,  
 D.M. Strom<sup>117</sup>, R. Stroynowski<sup>42</sup>, A. Strubig<sup>107</sup>, S.A. Stucci<sup>27</sup>, B. Stugu<sup>15</sup>, N.A. Styles<sup>44</sup>,  
 D. Su<sup>146</sup>, J. Su<sup>126</sup>, S. Suchek<sup>60a</sup>, Y. Sugaya<sup>119</sup>, M. Suk<sup>129</sup>, V.V. Sulin<sup>97</sup>, S. Sultansoy<sup>4c</sup>,  
 T. Sumida<sup>70</sup>, S. Sun<sup>58</sup>, X. Sun<sup>35a</sup>, J.E. Sundermann<sup>50</sup>, K. Suruliz<sup>152</sup>, G. Susinno<sup>39a,39b</sup>,  
 M.R. Sutton<sup>152</sup>, S. Suzuki<sup>68</sup>, M. Svatos<sup>128</sup>, M. Swiatlowski<sup>33</sup>, I. Sykora<sup>147a</sup>, T. Sykora<sup>130</sup>, D. Ta<sup>50</sup>,  
 C. Taccini<sup>135a,135b</sup>, K. Tackmann<sup>44</sup>, J. Taenzer<sup>162</sup>, A. Taffard<sup>167</sup>, R. Tafirout<sup>164a</sup>, N. Taiblum<sup>156</sup>,

H. Takai<sup>27</sup>, R. Takashima<sup>71</sup>, T. Takeshita<sup>143</sup>, Y. Takubo<sup>68</sup>, M. Talby<sup>87</sup>, A.A. Talyshev<sup>110,c</sup>, K.G. Tan<sup>90</sup>, J. Tanaka<sup>158</sup>, M. Tanaka<sup>160</sup>, R. Tanaka<sup>118</sup>, S. Tanaka<sup>68</sup>, R. Tanioka<sup>69</sup>, B.B. Tannenwald<sup>112</sup>, S. Tapia Araya<sup>34b</sup>, S. Tapprogge<sup>85</sup>, S. Tarem<sup>155</sup>, G.F. Tartarelli<sup>93a</sup>, P. Tas<sup>130</sup>, M. Tasevsky<sup>128</sup>, T. Tashiro<sup>70</sup>, E. Tassi<sup>39a,39b</sup>, A. Tavares Delgado<sup>127a,127b</sup>, Y. Tayalati<sup>136e</sup>, A.C. Taylor<sup>106</sup>, G.N. Taylor<sup>90</sup>, P.T.E. Taylor<sup>90</sup>, W. Taylor<sup>164b</sup>, F.A. Teischinger<sup>32</sup>, P. Teixeira-Dias<sup>79</sup>, K.K. Temming<sup>50</sup>, D. Temple<sup>145</sup>, H. Ten Kate<sup>32</sup>, P.K. Teng<sup>154</sup>, J.J. Teoh<sup>119</sup>, F. Tepel<sup>179</sup>, S. Terada<sup>68</sup>, K. Terashi<sup>158</sup>, J. Terron<sup>84</sup>, S. Terzo<sup>13</sup>, M. Testa<sup>49</sup>, R.J. Teuscher<sup>162,n</sup>, T. Theveneaux-Pelzer<sup>87</sup>, J.P. Thomas<sup>19</sup>, J. Thomas-Wilsker<sup>79</sup>, P.D. Thompson<sup>19</sup>, A.S. Thompson<sup>55</sup>, L.A. Thomsen<sup>180</sup>, E. Thomson<sup>123</sup>, M.J. Tibbetts<sup>16</sup>, R.E. Tice Torres<sup>87</sup>, V.O. Tikhomirov<sup>97,ar</sup>, Yu.A. Tikhonov<sup>110,c</sup>, S. Timoshenko<sup>99</sup>, P. Tipton<sup>180</sup>, S. Tisserant<sup>87</sup>, K. Todome<sup>160</sup>, T. Todorov<sup>5,\*</sup>, S. Todorova-Nova<sup>130</sup>, J. Tojo<sup>72</sup>, S. Tokár<sup>147a</sup>, K. Tokushuku<sup>68</sup>, E. Tolley<sup>58</sup>, L. Tomlinson<sup>86</sup>, M. Tomoto<sup>104</sup>, L. Tompkins<sup>146,as</sup>, K. Toms<sup>106</sup>, B. Tong<sup>58</sup>, P. Tornambe<sup>50</sup>, E. Torrence<sup>117</sup>, H. Torres<sup>145</sup>, E. Torró Pastor<sup>139</sup>, J. Toth<sup>87,at</sup>, F. Touchard<sup>87</sup>, D.R. Tovey<sup>142</sup>, T. Trefzger<sup>178</sup>, A. Tricoli<sup>27</sup>, I.M. Trigger<sup>164a</sup>, S. Trincas-Duvoid<sup>82</sup>, M.F. Tripiana<sup>13</sup>, W. Trischuk<sup>162</sup>, B. Trocme<sup>57</sup>, A. Trofymov<sup>44</sup>, C. Troncon<sup>93a</sup>, R. Trotta<sup>au</sup>, M. Trotter-McDonald<sup>16</sup>, M. Trovatelli<sup>173</sup>, L. Truong<sup>168a,168c</sup>, M. Trzebinski<sup>41</sup>, A. Trzupek<sup>41</sup>, J.C-L. Tseng<sup>121</sup>, P.V. Tsiareshka<sup>94</sup>, G. Tsipolitis<sup>10</sup>, N. Tsirintanis<sup>9</sup>, S. Tsiskaridze<sup>13</sup>, V. Tsiskaridze<sup>50</sup>, E.G. Tskhadadze<sup>53a</sup>, K.M. Tsui<sup>62a</sup>, I.I. Tsukerman<sup>98</sup>, V. Tsulaia<sup>16</sup>, S. Tsuno<sup>68</sup>, D. Tsybychev<sup>151</sup>, Y. Tu<sup>62b</sup>, A. Tudorache<sup>28b</sup>, V. Tudorache<sup>28b</sup>, A.N. Tuna<sup>58</sup>, S.A. Tuppuri<sup>22a,22b</sup>, S. Turchikhin<sup>67</sup>, D. Turecek<sup>129</sup>, D. Turgeman<sup>176</sup>, R. Turra<sup>93a,93b</sup>, P.M. Tuts<sup>37</sup>, M. Tyndel<sup>132</sup>, G. Uccelli<sup>22a,22b</sup>, I. Ueda<sup>158</sup>, M. Ughetto<sup>149a,149b</sup>, F. Ukegawa<sup>165</sup>, G. Unal<sup>32</sup>, A. Undrus<sup>27</sup>, G. Unel<sup>167</sup>, F.C. Ungaro<sup>90</sup>, Y. Unno<sup>68</sup>, C. Unverdorben<sup>101</sup>, J. Urban<sup>147b</sup>, P. Urquijo<sup>90</sup>, P. Urrejola<sup>85</sup>, G. Usai<sup>8</sup>, J. Usui<sup>68</sup>, L. Vacavant<sup>87</sup>, V. Vacek<sup>129</sup>, B. Vachon<sup>89</sup>, C. Valderanis<sup>101</sup>, E. Valdes Santurio<sup>149a,149b</sup>, N. Valencic<sup>108</sup>, S. Valentinetti<sup>22a,22b</sup>, A. Valero<sup>171</sup>, L. Valery<sup>13</sup>, S. Valkar<sup>130</sup>, J.A. Valls Ferrer<sup>171</sup>, W. Van Den Wollenberg<sup>108</sup>, P.C. Van Der Deijl<sup>108</sup>, H. van der Graaf<sup>108</sup>, N. van Eldik<sup>155</sup>, P. van Gemmeren<sup>6</sup>, J. Van Nieuwkoop<sup>145</sup>, I. van Vulpen<sup>108</sup>, M.C. van Woerden<sup>108</sup>, M. Vanadia<sup>133a,133b</sup>, W. Vandelli<sup>32</sup>, R. Vanguri<sup>123</sup>, A. Vaniachine<sup>161</sup>, P. Vankov<sup>108</sup>, G. Vardanyan<sup>181</sup>, R. Vari<sup>133a</sup>, E.W. Varnes<sup>7</sup>, T. Varol<sup>42</sup>, D. Varouchas<sup>82</sup>, A. Vartapetian<sup>8</sup>, K.E. Varvell<sup>153</sup>, J.G. Vasquez<sup>180</sup>, G.A. Vasquez<sup>34b</sup>, F. Vazeille<sup>36</sup>, T. Vazquez Schroeder<sup>89</sup>, J. Veatch<sup>56</sup>, V. Veeraraghavan<sup>7</sup>, L.M. Veloce<sup>162</sup>, F. Veloso<sup>127a,127c</sup>, S. Veneziano<sup>133a</sup>, A. Ventura<sup>75a,75b</sup>, M. Venturi<sup>173</sup>, N. Venturi<sup>162</sup>, A. Venturini<sup>25</sup>, V. Vercesi<sup>122a</sup>, M. Verducci<sup>133a,133b</sup>, W. Verkerke<sup>108</sup>, J.C. Vermeulen<sup>108</sup>, A. Vest<sup>46,av</sup>, M.C. Vetterli<sup>145,d</sup>, O. Viazlo<sup>83</sup>, I. Vichou<sup>170,\*</sup>, T. Vickey<sup>142</sup>, O.E. Vickey Boeriu<sup>142</sup>, G.H.A. Viehhauser<sup>121</sup>, S. Viel<sup>16</sup>, L. Vigani<sup>121</sup>, M. Villa<sup>22a,22b</sup>, M. Villaplana Perez<sup>93a,93b</sup>, E. Vilucchi<sup>49</sup>, M.G. Vinciter<sup>31</sup>, V.B. Vinogradov<sup>67</sup>, C. Vittori<sup>22a,22b</sup>, I. Vivarelli<sup>152</sup>, S. Vlachos<sup>10</sup>, M. Vlasak<sup>129</sup>, M. Vogel<sup>179</sup>, P. Vokac<sup>129</sup>, G. Volpi<sup>125a,125b</sup>, M. Volpi<sup>90</sup>, H. von der Schmitt<sup>102</sup>, E. von Toerne<sup>23</sup>, V. Vorobel<sup>130</sup>, K. Vorobev<sup>99</sup>, M. Vos<sup>171</sup>, R. Voss<sup>32</sup>, J.H. Vossebeld<sup>76</sup>, N. Vranjes<sup>14</sup>, M. Vranjes Milosavljevic<sup>14</sup>, V. Vrba<sup>128</sup>, M. Vreeswijk<sup>108</sup>, R. Vuillermet<sup>32</sup>, I. Vukotic<sup>33</sup>, Z. Vykydal<sup>129</sup>, P. Wagner<sup>23</sup>, W. Wagner<sup>179</sup>, H. Wahlberg<sup>73</sup>, S. Wahrmund<sup>46</sup>, J. Wakabayashi<sup>104</sup>, J. Walder<sup>74</sup>, R. Walker<sup>101</sup>, W. Walkowiak<sup>144</sup>, V. Wallangen<sup>149a,149b</sup>, C. Wang<sup>35b</sup>, C. Wang<sup>140,87</sup>, F. Wang<sup>177</sup>, H. Wang<sup>16</sup>, H. Wang<sup>42</sup>, J. Wang<sup>44</sup>, J. Wang<sup>153</sup>, K. Wang<sup>89</sup>, R. Wang<sup>6</sup>, S.M. Wang<sup>154</sup>, T. Wang<sup>23</sup>, T. Wang<sup>37</sup>, W. Wang<sup>59</sup>, C. Wanotayaroj<sup>117</sup>, A. Warburton<sup>89</sup>, C.P. Ward<sup>30</sup>, D.R. Wardrope<sup>80</sup>, A. Washbrook<sup>48</sup>, P.M. Watkins<sup>19</sup>, A.T. Watson<sup>19</sup>, M.F. Watson<sup>19</sup>, G. Watts<sup>139</sup>, S. Watts<sup>86</sup>, B.M. Waugh<sup>80</sup>, S. Webb<sup>85</sup>, M.S. Weber<sup>18</sup>, S.W. Weber<sup>178</sup>, S.A. Weber<sup>31</sup>, J.S. Webster<sup>6</sup>, A.R. Weidberg<sup>121</sup>, B. Weinert<sup>63</sup>, J. Weingarten<sup>56</sup>, C. Weiser<sup>50</sup>, H. Weits<sup>108</sup>, P.S. Wells<sup>32</sup>, T. Wenaus<sup>27</sup>, T. Wengler<sup>32</sup>, S. Wenig<sup>32</sup>, N. Wermes<sup>23</sup>, M. Werner<sup>50</sup>, M.D. Werner<sup>66</sup>, P. Werner<sup>32</sup>, M. Wessels<sup>60a</sup>, J. Wetter<sup>166</sup>, K. Whalen<sup>117</sup>, N.L. Whallon<sup>139</sup>, A.M. Wharton<sup>74</sup>, A. White<sup>8</sup>, M.J. White<sup>1</sup>, R. White<sup>34b</sup>, D. Whiteson<sup>167</sup>, F.J. Wickens<sup>132</sup>, W. Wiedenmann<sup>177</sup>, M. Wielers<sup>132</sup>,

C. Wigglesworth<sup>38</sup>, L.A.M. Wiik-Fuchs<sup>23</sup>, A. Wildauer<sup>102</sup>, F. Wilk<sup>86</sup>, H.G. Wilkens<sup>32</sup>, H.H. Williams<sup>123</sup>, S. Williams<sup>108</sup>, C. Willis<sup>92</sup>, S. Willocq<sup>88</sup>, J.A. Wilson<sup>19</sup>, I. Wingerter-Seez<sup>5</sup>, F. Winklmeier<sup>117</sup>, O.J. Winston<sup>152</sup>, B.T. Winter<sup>23</sup>, M. Wittgen<sup>146</sup>, J. Wittkowski<sup>101</sup>, T.M.H. Wolf<sup>108</sup>, M.W. Wolter<sup>41</sup>, H. Wolters<sup>127a,127c</sup>, S.D. Worm<sup>132</sup>, B.K. Wosiek<sup>41</sup>, J. Wotschack<sup>32</sup>, M.J. Woudstra<sup>86</sup>, K.W. Wozniak<sup>41</sup>, M. Wu<sup>57</sup>, M. Wu<sup>33</sup>, S.L. Wu<sup>177</sup>, X. Wu<sup>51</sup>, Y. Wu<sup>91</sup>, T.R. Wyatt<sup>86</sup>, B.M. Wynne<sup>48</sup>, S. Xella<sup>38</sup>, D. Xu<sup>35a</sup>, L. Xu<sup>27</sup>, B. Yabsley<sup>153</sup>, S. Yacoob<sup>148a</sup>, D. Yamaguchi<sup>160</sup>, Y. Yamaguchi<sup>119</sup>, A. Yamamoto<sup>68</sup>, S. Yamamoto<sup>158</sup>, T. Yamanaka<sup>158</sup>, K. Yamauchi<sup>104</sup>, Y. Yamazaki<sup>69</sup>, Z. Yan<sup>24</sup>, H. Yang<sup>141</sup>, H. Yang<sup>177</sup>, Y. Yang<sup>154</sup>, Z. Yang<sup>15</sup>, W.-M. Yao<sup>16</sup>, Y.C. Yap<sup>82</sup>, Y. Yasu<sup>68</sup>, E. Yatsenko<sup>5</sup>, K.H. Yau Wong<sup>23</sup>, J. Ye<sup>42</sup>, S. Ye<sup>27</sup>, I. Yeletsikh<sup>67</sup>, E. Yildirim<sup>85</sup>, K. Yorita<sup>175</sup>, R. Yoshida<sup>6</sup>, K. Yoshihara<sup>123</sup>, C. Young<sup>146</sup>, C.J.S. Young<sup>32</sup>, S. Youssef<sup>24</sup>, D.R. Yu<sup>16</sup>, J. Yu<sup>8</sup>, J.M. Yu<sup>91</sup>, J. Yu<sup>66</sup>, L. Yuan<sup>69</sup>, S.P.Y. Yuen<sup>23</sup>, I. Yusuff<sup>30,aw</sup>, B. Zabinski<sup>41</sup>, R. Zaidan<sup>65</sup>, A.M. Zaitsev<sup>131,ag</sup>, N. Zakharuk<sup>44</sup>, J. Zalieckas<sup>15</sup>, A. Zaman<sup>151</sup>, S. Zambito<sup>58</sup>, L. Zanello<sup>133a,133b</sup>, D. Zanzi<sup>90</sup>, C. Zeitnitz<sup>179</sup>, M. Zeman<sup>129</sup>, A. Zemla<sup>40a</sup>, J.C. Zeng<sup>170</sup>, Q. Zeng<sup>146</sup>, O. Zenin<sup>131</sup>, T. Ženiš<sup>147a</sup>, D. Zerwas<sup>118</sup>, D. Zhang<sup>91</sup>, F. Zhang<sup>177</sup>, G. Zhang<sup>59,aq</sup>, H. Zhang<sup>35b</sup>, J. Zhang<sup>6</sup>, L. Zhang<sup>50</sup>, M. Zhang<sup>170</sup>, R. Zhang<sup>23</sup>, R. Zhang<sup>59,ax</sup>, X. Zhang<sup>140</sup>, Z. Zhang<sup>118</sup>, X. Zhao<sup>42</sup>, Y. Zhao<sup>140</sup>, Z. Zhao<sup>59</sup>, A. Zhemchugov<sup>67</sup>, J. Zhong<sup>121</sup>, B. Zhou<sup>91</sup>, C. Zhou<sup>177</sup>, L. Zhou<sup>37</sup>, L. Zhou<sup>42</sup>, M. Zhou<sup>151</sup>, N. Zhou<sup>35c</sup>, C.G. Zhu<sup>140</sup>, H. Zhu<sup>35a</sup>, J. Zhu<sup>91</sup>, Y. Zhu<sup>59</sup>, X. Zhuang<sup>35a</sup>, K. Zhukov<sup>97</sup>, A. Zibell<sup>178</sup>, D. Zieminska<sup>63</sup>, N.I. Zimine<sup>67</sup>, C. Zimmermann<sup>85</sup>, S. Zimmermann<sup>50</sup>, Z. Zinonos<sup>56</sup>, M. Zinser<sup>85</sup>, M. Ziolkowski<sup>144</sup>, L. Živković<sup>14</sup>, G. Zobernig<sup>177</sup>, A. Zoccoli<sup>22a,22b</sup>, M. zur Nedden<sup>17</sup> and L. Zwalinski<sup>32</sup>

<sup>1</sup> Department of Physics, University of Adelaide, Adelaide, Australia

<sup>2</sup> Physics Department, SUNY Albany, Albany NY, United States of America

<sup>3</sup> Department of Physics, University of Alberta, Edmonton AB, Canada

<sup>4</sup> (a) Department of Physics, Ankara University, Ankara; (b) Istanbul Aydin University, Istanbul; (c) Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey

<sup>5</sup> LAPP, CNRS/IN2P3 and Université Savoie Mont Blanc, Annecy-le-Vieux, France

<sup>6</sup> High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America

<sup>7</sup> Department of Physics, University of Arizona, Tucson AZ, United States of America

<sup>8</sup> Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America

<sup>9</sup> Physics Department, University of Athens, Athens, Greece

<sup>10</sup> Physics Department, National Technical University of Athens, Zografou, Greece

<sup>11</sup> Department of Physics, The University of Texas at Austin, Austin TX, United States of America

<sup>12</sup> Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

<sup>13</sup> Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain, Spain

<sup>14</sup> Institute of Physics, University of Belgrade, Belgrade, Serbia

<sup>15</sup> Department for Physics and Technology, University of Bergen, Bergen, Norway

<sup>16</sup> Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America

<sup>17</sup> Department of Physics, Humboldt University, Berlin, Germany

<sup>18</sup> Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

<sup>19</sup> School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

<sup>20</sup> (a) Department of Physics, Bogazici University, Istanbul; (b) Department of Physics Engineering, Gaziantep University, Gaziantep; (d) Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey; (e) Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey, Turkey

<sup>21</sup> Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia

- <sup>22</sup> <sup>(a)</sup> INFN Sezione di Bologna; <sup>(b)</sup> Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy
- <sup>23</sup> Physikalisches Institut, University of Bonn, Bonn, Germany
- <sup>24</sup> Department of Physics, Boston University, Boston MA, United States of America
- <sup>25</sup> Department of Physics, Brandeis University, Waltham MA, United States of America
- <sup>26</sup> <sup>(a)</sup> Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; <sup>(b)</sup> Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora; <sup>(c)</sup> Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; <sup>(d)</sup> Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
- <sup>27</sup> Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- <sup>28</sup> <sup>(a)</sup> Transilvania University of Brasov, Brasov, Romania; <sup>(b)</sup> National Institute of Physics and Nuclear Engineering, Bucharest; <sup>(c)</sup> National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca; <sup>(d)</sup> University Politehnica Bucharest, Bucharest; <sup>(e)</sup> West University in Timisoara, Timisoara, Romania
- <sup>29</sup> Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- <sup>30</sup> Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- <sup>31</sup> Department of Physics, Carleton University, Ottawa ON, Canada
- <sup>32</sup> CERN, Geneva, Switzerland
- <sup>33</sup> Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
- <sup>34</sup> <sup>(a)</sup> Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; <sup>(b)</sup> Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- <sup>35</sup> <sup>(a)</sup> Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; <sup>(b)</sup> Department of Physics, Nanjing University, Jiangsu; <sup>(c)</sup> Physics Department, Tsinghua University, Beijing 100084, China
- <sup>36</sup> Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France
- <sup>37</sup> Nevis Laboratory, Columbia University, Irvington NY, United States of America
- <sup>38</sup> Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
- <sup>39</sup> <sup>(a)</sup> INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; <sup>(b)</sup> Dipartimento di Fisica, Università della Calabria, Rende, Italy
- <sup>40</sup> <sup>(a)</sup> AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; <sup>(b)</sup> Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
- <sup>41</sup> Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
- <sup>42</sup> Physics Department, Southern Methodist University, Dallas TX, United States of America
- <sup>43</sup> Physics Department, University of Texas at Dallas, Richardson TX, United States of America
- <sup>44</sup> DESY, Hamburg and Zeuthen, Germany
- <sup>45</sup> Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- <sup>46</sup> Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
- <sup>47</sup> Department of Physics, Duke University, Durham NC, United States of America
- <sup>48</sup> SUPA — School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- <sup>49</sup> INFN Laboratori Nazionali di Frascati, Frascati, Italy
- <sup>50</sup> Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany
- <sup>51</sup> Section de Physique, Université de Genève, Geneva, Switzerland
- <sup>52</sup> <sup>(a)</sup> INFN Sezione di Genova; <sup>(b)</sup> Dipartimento di Fisica, Università di Genova, Genova, Italy
- <sup>53</sup> <sup>(a)</sup> E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi; <sup>(b)</sup> High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- <sup>54</sup> II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- <sup>55</sup> SUPA — School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- <sup>56</sup> II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- <sup>57</sup> Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
- <sup>58</sup> Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America



- <sup>59</sup> *Department of Modern Physics, University of Science and Technology of China, Anhui, China*
- <sup>60</sup> <sup>(a)</sup> *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* <sup>(b)</sup> *Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* <sup>(c)</sup> *ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany*
- <sup>61</sup> *Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
- <sup>62</sup> <sup>(a)</sup> *Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong;* <sup>(b)</sup> *Department of Physics, The University of Hong Kong, Hong Kong;* <sup>(c)</sup> *Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- <sup>63</sup> *Department of Physics, Indiana University, Bloomington IN, United States of America*
- <sup>64</sup> *Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
- <sup>65</sup> *University of Iowa, Iowa City IA, United States of America*
- <sup>66</sup> *Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America*
- <sup>67</sup> *Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia*
- <sup>68</sup> *KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
- <sup>69</sup> *Graduate School of Science, Kobe University, Kobe, Japan*
- <sup>70</sup> *Faculty of Science, Kyoto University, Kyoto, Japan*
- <sup>71</sup> *Kyoto University of Education, Kyoto, Japan*
- <sup>72</sup> *Department of Physics, Kyushu University, Fukuoka, Japan*
- <sup>73</sup> *Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
- <sup>74</sup> *Physics Department, Lancaster University, Lancaster, United Kingdom*
- <sup>75</sup> <sup>(a)</sup> *INFN Sezione di Lecce;* <sup>(b)</sup> *Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
- <sup>76</sup> *Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
- <sup>77</sup> *Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia*
- <sup>78</sup> *School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
- <sup>79</sup> *Department of Physics, Royal Holloway University of London, Surrey, United Kingdom*
- <sup>80</sup> *Department of Physics and Astronomy, University College London, London, United Kingdom*
- <sup>81</sup> *Louisiana Tech University, Ruston LA, United States of America*
- <sup>82</sup> *Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France*
- <sup>83</sup> *Fysiska institutionen, Lunds universitet, Lund, Sweden*
- <sup>84</sup> *Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain*
- <sup>85</sup> *Institut für Physik, Universität Mainz, Mainz, Germany*
- <sup>86</sup> *School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
- <sup>87</sup> *CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France*
- <sup>88</sup> *Department of Physics, University of Massachusetts, Amherst MA, United States of America*
- <sup>89</sup> *Department of Physics, McGill University, Montreal QC, Canada*
- <sup>90</sup> *School of Physics, University of Melbourne, Victoria, Australia*
- <sup>91</sup> *Department of Physics, The University of Michigan, Ann Arbor MI, United States of America*
- <sup>92</sup> *Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America*
- <sup>93</sup> <sup>(a)</sup> *INFN Sezione di Milano;* <sup>(b)</sup> *Dipartimento di Fisica, Università di Milano, Milano, Italy*
- <sup>94</sup> *B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus*
- <sup>95</sup> *National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus*
- <sup>96</sup> *Group of Particle Physics, University of Montreal, Montreal QC, Canada*
- <sup>97</sup> *P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
- <sup>98</sup> *Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia*
- <sup>99</sup> *National Research Nuclear University MEPhI, Moscow, Russia*
- <sup>100</sup> *D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*

- 101 *Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*  
 102 *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*  
 103 *Nagasaki Institute of Applied Science, Nagasaki, Japan*  
 104 *Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*  
 105 <sup>(a)</sup> *INFN Sezione di Napoli;* <sup>(b)</sup> *Dipartimento di Fisica, Università di Napoli, Napoli, Italy*  
 106 *Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America*  
 107 *Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*  
 108 *Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*  
 109 *Department of Physics, Northern Illinois University, DeKalb IL, United States of America*  
 110 *Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia*  
 111 *Department of Physics, New York University, New York NY, United States of America*  
 112 *Ohio State University, Columbus OH, United States of America*  
 113 *Faculty of Science, Okayama University, Okayama, Japan*  
 114 *Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America*  
 115 *Department of Physics, Oklahoma State University, Stillwater OK, United States of America*  
 116 *Palacký University, RCPTM, Olomouc, Czech Republic*  
 117 *Center for High Energy Physics, University of Oregon, Eugene OR, United States of America*  
 118 *LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*  
 119 *Graduate School of Science, Osaka University, Osaka, Japan*  
 120 *Department of Physics, University of Oslo, Oslo, Norway*  
 121 *Department of Physics, Oxford University, Oxford, United Kingdom*  
 122 <sup>(a)</sup> *INFN Sezione di Pavia;* <sup>(b)</sup> *Dipartimento di Fisica, Università di Pavia, Pavia, Italy*  
 123 *Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America*  
 124 *National Research Centre “Kurchatov Institute” B.P.Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia*  
 125 <sup>(a)</sup> *INFN Sezione di Pisa;* <sup>(b)</sup> *Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*  
 126 *Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America*  
 127 <sup>(a)</sup> *Laboratório de Instrumentação e Física Experimental de Partículas — LIP, Lisboa;* <sup>(b)</sup> *Faculdade de Ciências, Universidade de Lisboa, Lisboa;* <sup>(c)</sup> *Department of Physics, University of Coimbra, Coimbra;* <sup>(d)</sup> *Centro de Física Nuclear da Universidade de Lisboa, Lisboa;* <sup>(e)</sup> *Departamento de Física, Universidade do Minho, Braga;* <sup>(f)</sup> *Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada (Spain);* <sup>(g)</sup> *Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*  
 128 *Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic*  
 129 *Czech Technical University in Prague, Praha, Czech Republic*  
 130 *Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic*  
 131 *State Research Center Institute for High Energy Physics (Protvino), NRC KI, Russia*  
 132 *Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*  
 133 <sup>(a)</sup> *INFN Sezione di Roma;* <sup>(b)</sup> *Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*  
 134 <sup>(a)</sup> *INFN Sezione di Roma Tor Vergata;* <sup>(b)</sup> *Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*  
 135 <sup>(a)</sup> *INFN Sezione di Roma Tre;* <sup>(b)</sup> *Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*  
 136 <sup>(a)</sup> *Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies — Université Hassan II, Casablanca;* <sup>(b)</sup> *Centre National de l’Energie des Sciences Techniques Nucleaires, Rabat;* <sup>(c)</sup> *Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;* <sup>(d)</sup> *Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda;* <sup>(e)</sup> *Faculté des sciences, Université Mohammed V, Rabat, Morocco*

- 137 *DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay*  
 (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France  
 138 *Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA,*  
*United States of America*  
 139 *Department of Physics, University of Washington, Seattle WA, United States of America*  
 140 *School of Physics, Shandong University, Shandong, China*  
 141 *Department of Physics and Astronomy, Shanghai Key Laboratory for Particle Physics and*  
*Cosmology, Shanghai Jiao Tong University, Shanghai; (also affiliated with PKU-CHEP), China*  
 142 *Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*  
 143 *Department of Physics, Shinshu University, Nagano, Japan*  
 144 *Fachbereich Physik, Universität Siegen, Siegen, Germany*  
 145 *Department of Physics, Simon Fraser University, Burnaby BC, Canada*  
 146 *SLAC National Accelerator Laboratory, Stanford CA, United States of America*  
 147 <sup>(a)</sup> *Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava;* <sup>(b)</sup>  
*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of*  
*Sciences, Kosice, Slovak Republic*  
 148 <sup>(a)</sup> *Department of Physics, University of Cape Town, Cape Town;* <sup>(b)</sup> *Department of Physics,*  
*University of Johannesburg, Johannesburg;* <sup>(c)</sup> *School of Physics, University of the Witwatersrand,*  
*Johannesburg, South Africa*  
 149 <sup>(a)</sup> *Department of Physics, Stockholm University;* <sup>(b)</sup> *The Oskar Klein Centre, Stockholm, Sweden*  
 150 *Physics Department, Royal Institute of Technology, Stockholm, Sweden*  
 151 *Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY,*  
*United States of America*  
 152 *Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*  
 153 *School of Physics, University of Sydney, Sydney, Australia*  
 154 *Institute of Physics, Academia Sinica, Taipei, Taiwan*  
 155 *Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel*  
 156 *Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv,*  
*Israel*  
 157 *Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*  
 158 *International Center for Elementary Particle Physics and Department of Physics, The University*  
*of Tokyo, Tokyo, Japan*  
 159 *Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*  
 160 *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*  
 161 *Tomsk State University, Tomsk, Russia, Russia*  
 162 *Department of Physics, University of Toronto, Toronto ON, Canada*  
 163 <sup>(a)</sup> *INFN-TIFPA;* <sup>(b)</sup> *University of Trento, Trento, Italy, Italy*  
 164 <sup>(a)</sup> *TRIUMF, Vancouver BC;* <sup>(b)</sup> *Department of Physics and Astronomy, York University, Toronto*  
*ON, Canada*  
 165 *Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science*  
*and Engineering, University of Tsukuba, Tsukuba, Japan*  
 166 *Department of Physics and Astronomy, Tufts University, Medford MA, United States of America*  
 167 *Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of*  
*America*  
 168 <sup>(a)</sup> *INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine;* <sup>(b)</sup> *ICTP, Trieste;* <sup>(c)</sup>  
*Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy*  
 169 *Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*  
 170 *Department of Physics, University of Illinois, Urbana IL, United States of America*  
 171 *Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear*  
*and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona*  
*(IMB-CNM), University of Valencia and CSIC, Valencia, Spain*  
 172 *Department of Physics, University of British Columbia, Vancouver BC, Canada*

- <sup>173</sup> *Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada*  
<sup>174</sup> *Department of Physics, University of Warwick, Coventry, United Kingdom*  
<sup>175</sup> *Waseda University, Tokyo, Japan*  
<sup>176</sup> *Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel*  
<sup>177</sup> *Department of Physics, University of Wisconsin, Madison WI, United States of America*  
<sup>178</sup> *Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany*  
<sup>179</sup> *Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*  
<sup>180</sup> *Department of Physics, Yale University, New Haven CT, United States of America*  
<sup>181</sup> *Yerevan Physics Institute, Yerevan, Armenia*  
<sup>182</sup> *Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
- <sup>a</sup> *Also at Department of Physics, King's College London, London, United Kingdom*  
<sup>b</sup> *Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*  
<sup>c</sup> *Also at Novosibirsk State University, Novosibirsk, Russia*  
<sup>d</sup> *Also at TRIUMF, Vancouver BC, Canada*  
<sup>e</sup> *Also at Department of Physics & Astronomy, University of Louisville, Louisville, KY, United States of America*  
<sup>f</sup> *Also at Physics Department, An-Najah National University, Nablus, Palestine*  
<sup>g</sup> *Also at Department of Physics, California State University, Fresno CA, United States of America*  
<sup>h</sup> *Also at Department of Physics, University of Fribourg, Fribourg, Switzerland*  
<sup>i</sup> *Associated at Institute for Theoretical Physics, University of Amsterdam, Amsterdam, Netherlands*  
<sup>j</sup> *Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain*  
<sup>k</sup> *Also at Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Portugal*  
<sup>l</sup> *Also at Tomsk State University, Tomsk, Russia, Russia*  
<sup>m</sup> *Also at Università di Napoli Parthenope, Napoli, Italy*  
<sup>n</sup> *Also at Institute of Particle Physics (IPP), Canada*  
<sup>o</sup> *Also at National Institute of Physics and Nuclear Engineering, Bucharest, Romania*  
<sup>p</sup> *Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia*  
<sup>q</sup> *Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America*  
<sup>r</sup> *Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa*  
<sup>s</sup> *Also at Louisiana Tech University, Ruston LA, United States of America*  
<sup>t</sup> *Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain*  
<sup>u</sup> *Also at Graduate School of Science, Osaka University, Osaka, Japan*  
<sup>v</sup> *Also at Department of Physics, National Tsing Hua University, Taiwan*  
<sup>w</sup> *Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*  
<sup>x</sup> *Also at Department of Physics, The University of Texas at Austin, Austin TX, United States of America*  
<sup>y</sup> *Also at CERN, Geneva, Switzerland*  
<sup>z</sup> *Also at Georgian Technical University (GTU), Tbilisi, Georgia*  
<sup>aa</sup> *Also at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan*  
<sup>ab</sup> *Also at Manhattan College, New York NY, United States of America*  
<sup>ac</sup> *Also at Hellenic Open University, Patras, Greece*  
<sup>ad</sup> *Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan*  
<sup>ae</sup> *Also at School of Physics, Shandong University, Shandong, China*  
<sup>af</sup> *Also at Department of Physics, California State University, Sacramento CA, United States of America*

- <sup>ag</sup> Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia
- <sup>ah</sup> Also at Section de Physique, Université de Genève, Geneva, Switzerland
- <sup>ai</sup> Also at Eotvos Lorand University, Budapest, Hungary
- <sup>aj</sup> Also at Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
- <sup>ak</sup> Also at International School for Advanced Studies (SISSA), Trieste, Italy
- <sup>al</sup> Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- <sup>am</sup> Associated at Instituto de Fisica Corpuscular (IFIC) and Departamento de Fisica Atomica, Molecular y Nuclear and Departamento de Ingenieria Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
- <sup>an</sup> Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
- <sup>ao</sup> Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria
- <sup>ap</sup> Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
- <sup>aq</sup> Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- <sup>ar</sup> Also at National Research Nuclear University MEPhI, Moscow, Russia
- <sup>as</sup> Also at Department of Physics, Stanford University, Stanford CA, United States of America
- <sup>at</sup> Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
- <sup>au</sup> Associated at Department of Physics, Imperial College, London, United Kingdom
- <sup>av</sup> Also at Flensburg University of Applied Sciences, Flensburg, Germany
- <sup>aw</sup> Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia
- <sup>ax</sup> Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- \* Deceased